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INVESTIGATION OF THE ENVIRONMENTAL CONSEQUENCES OF DISPOSAL OF THE LITHIUM-ORGANIC ELECTROLYTE/SO_2 BATTERY

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		Soil Shake Tests

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report contains preliminary recommendations for the disposal of small and large quantities of lithium-organic electrolyte/SO_2 batteries based upon a literature review for toxicity of the battery components and laboratory tests of leachate from cross-sectioned batteries. The leaching tests identified significant quantities of cyanide from discharged batteries.

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I. INTRODUCTION AND SUMMARY

The lithium-organic electrolyte-SO_2 battery is a new primary battery which has many advantages over existing primary batteries. The superior electrical properties of the battery are produced by an electrochemical system which contains some unconventional materials and uses a non-aqueous electrolyte. The major components of the battery system investigated include lithium metal as the anode, a carbon cathode consisting of a mixture of carbon and teflon on a support screen, and an electrolyte consisting of lithium bromide and sulfur dioxide dissolved in acetonitrile (propylene carbonate may be mixed with the solvent). Conventional materials are used for separators inside the battery and for the outside jacket.

Because of the potential hazardous or toxic nature of some of the battery components, the U.S. Army contracted for a study on the environmental consequences of the disposal of the battery by Army personnel. The objective of this program was to provide recommendations for low cost environmentally acceptable disposal procedures for both large and small quantities of the battery.

In order to accomplish the objective, three tasks have been performed. The first task involved a number of subtasks. First, a collection of available toxicity data and an evaluation of the relative hazardousness of the components of the battery were made. Then a listing and description of standard disposal practices for hazardous wastes was compiled. Next, State and Federal regulations pertaining specifically to disposal of the lithium battery were sought. Since none were found, general hazardous waste disposal regulations were compiled.

Finally a preliminary assessment was made of the standard disposal practices as they relate to the problem of the lithium cell and its chemical constituents.

The second task involved a laboratory investigation of selected land disposal procedures to evaluate which, if any, is the most acceptable procedure. A major effort on this task was devoted to laboratory testing. A test plan was devised to provide information in the following areas:

(1) battery component solubility and hydrolysis product identification;
(2) soil adsorption and precipitation; and
(3) soil leachate testing.

The results of the testing program indicated the following:

- that many of the battery components are quite soluble in water;
- that cyanide was detected in significant concentrations in a solution made by cutting open a discharged cell and immersing it in water;
- that once the components of the battery were exposed to an aqueous environment several days were required for the component concentrations to reach some sort of equilibrium;
- the sandy loam soil proved to be relatively non-adsorbent to the battery components, whereas the test data on the silty clay and silty loam soils were inconclusive; and
- that the column leachate test using sandy loam soil showed the presence of significant quantities of cyanide in the leachate from two discharged cells.

The third task of the program was the preparation of preliminary disposal recommendations based upon the results of the first two tasks. These recommendations considered both large quantity and small quantity disposal.

Versar's opinion, based on the results of data generated to date, is that secured landfills or lined disposal ponds are the only environmentally acceptable disposal alternatives. Disposal would be limited to these methods because of the quantities of cyanide released from discharged cells. The results of the laboratory studies showed that a discharged

D-cell liberates as much as 205 mg of cyanide. This quantity of cyanide would have a lethal effect on three humans. Although it is recognized that this quantity of cyanide could be diluted with a large quantity of water to below the toxic limits (approximately 1,000 liters or 270 gallons would be required per cell), there is no way to accurately predict how or where this would occur in a normal landfill situation. Furthermore, the purpose of a controlled disposal procedure is to dispose of the waste in a manner which precludes or minimizes release to the environment of toxic or hazardous materials.

It is recommended that further investigations should be made to more fully evaluate the lithium cells and its chemical components. This work should consist first of additional analysis of chemical components from both live and discharged lithium cells. To date analysis has been done on only about six discharged cells in a fully discharged state. The level to which the cells were discharged may not be representative of 'typical' conditions generated for cells in field maneuvers. Also, the analysis of six cells has not provided an adeuqate base upon which to statistically evaluate the results at different discharge levels.

Second, the column leachate studies should be continued until sorption of cell chemical components can be evaluated for silty clay and clay type soils. To date, data was available only for the relatively high permeability and non-sorptive sandy type soil. Data from the lower permeability and typically more sorptive soils may indicate cell component concentrations are reduced by contact with these soils.

Results of additional work would provide a more complete data base upon which to fully characterize the chemical constituents of live and a range of discharged lithium cells. Future disposal recommendations based on this data and the leachate column studies could be formulated with much greater reliability.

A possibility exists that the chemical composition of the lithium-organic electrolyte/SO_2 cell can be changed or modified to eliminate or greatly reduce the formation of cyanide, according to the U.S. Army. If

this could be accomplished, then other disposal options less stringent than those recommended would probably provide adequate environmental protection from lithium and sulfur dioxide toxicity. However, it is recommended that for any such change in battery composition, the disposal options should be re-evaluated based upon laboratory studies.

II. TECHNICAL RESULTS AND DISCUSSION

A. Description of the Battery

The lithium-organic electrolyte-SO_2 battery is a new primary battery. It has several advantages over existing batteries. These advantages include higher voltage, longer shelf life, better low temperature performance, higher capacity, greater power densities, and lighter weight. Lithium batteries are still being developed by companies in the U.S., but several companies are currently producing this battery commercially in limited quantities.

The chemical composition of the battery and the toxicological and hazardous properties of the battery components are described in the following sections.

1. Chemical Description

The lithium-organic electrolyte/SO_2 cell contains lithium metal as the anode (usually in the form of a ribbon) with acetylene black and sulfur dioxide as the cathode. The electrolyte is non-aqueous since lithium reacts vigorously with water to generate hydrogen gas and heat. The electrolyte is an organic liquid containing a soluble salt but no water. The electrolytes which have been used include acetonitrile and propylene carbonate. The salt used in the electrolyte is lithium bromide.

During discharge of the battery, the dissolved SO_2 is reduced to sulfite at the cathode while the metallic lithium anode is converted to lithium ions. As a results, the spent batteries contain organic solvent saturated with dissolved lithium salts (including sulfites).

There is also an apparent chemical reaction of the acetonitrile solvent to produce cyanide ion. Although under normal conditions acetonitrile is stable, a chemical reaction with lithium, in the absence of SO_2 causes cyanide to be formed.

The typical composition of a live lithium-organic electrolyte/SO_2 D-cell is as follows:

1. Lithium Anode - 4.2 grams.
2. Carbon cathode consisting of an aluminum support screen, and 80% acetylene black, 20% teflon mixture - 13 grams.
3. Polypropylene separator - 1.0 gram.
4. Electrolyte consists of 24.5 grams of sulfur dioxide, 2 grams of lithium bromide, and 8.5 grams of acetonitrile.

The composition of a discharged battery differs in that lithium dithionite ($Li_2S_2O_4$) is formed from the lithium metal and sulfur dioxide and some of the acetonitrile is broken down to yield cyanide.

2. Environmental Description

Several of the components of the battery have toxic or hazardous properties that affect the selection of acceptable disposal methods. A thorough literature review of the toxicity and hazardousness of these components was conducted and the results are summarized below. Complete toxicity profiles of the substances are found in Appendix A.

Carbon, teflon and polypropylene were reviewed and found to be innocuous in the context of battery disposal.

Acetonitrile

Acetonitrile was found to be practically non-toxic to mammals, fish, birds and amphibians. Although inhalation of the vapor in a closed room has caused human death, it does not represent a serious airborne problem because of the high concentration required to produce toxic effects. Acetonitrile is flammable and is a potential hazard when handling the batteries. The exothermic reaction between metallic lithium and water can ignite acetonitrile, causing a fire or explosion. However, decomposition of acetonitrile into methyl- and cyanide groups is the major toxicological problem associated with this compound.

Cyanide

Although cyanide is not a component of the battery, it was reviewed because its presence was confirmed in laboratory tests designed to identify component species in an aqueous solution. Cyanide is acutely toxic

to mammals, fish, invertebrates, protozoa, plants and bacteria. The cyanide ion is less acutely lethal than hydrogen cyanide. The toxic effect of cyanide is due to its interference with the enzymes associated with cellular oxidation, so that cells asphyxiate. Cyanide is not biologically accumulated and at sub-toxic dosages it is rapidly changed in the body to relatively non-toxic substances (e.g., thiocyanate). Hydrogen cyanide (HCN) and most cyanide salts are extremely soluble in water. HCN is volatile and flammable.

Lithium and its Compounds

Metallic lithium (Li) and lithium bromide (LiBr) are components of the battery. Two other lithium compounds were also studied: lithium hydroxide (LiOH), which is formed by the reaction between lithium and water; and lithium dithionite ($Li_2S_2O_4$), which occurs as a result of the chemical oxidation of lithium and reduction of sulfur dioxide during battery discharge.

The toxicity of metallic lithium was not considered germane to this study because it reacts immediately on contact with water or water vapor to form LiOH and hydrogen gas. Lithium hydroxide (LiOH) is a strong base and its toxicity is due to its corrosive action on skin and internal tissues. When dissolved in water, an increase in pH occurs which could be toxic to aquatic and soil biota. Lithium dithionite ($Li_2S_2O_4$) forms a slightly alkaline solution in water which is corrosive to skin. No toxicity data are available for $Li_2S_2O_4$, but data on $Na_2S_2O_4$ (sodium dithionite) indicate that the $S_2O_4^{=}$ group is practically non-toxic to mammals. Lithium bromide (LiBr) is also practically non-toxic to mammals. The major groups of organisms threatened by the lithium compounds are plants and freshwater invertebrates. Very small amounts (1-30 mg/l) of lithium compounds added to soil have caused toxic effects to a variety of plants, especially citrus. Concentrations of lithium salts as low as 7.2 mg/l have immobilized freshwater invertebrates. This concentration is several orders of magnitude lower than with the corresponding sodium and calcium salts. Lithium metal can cause an airborne hazard when it reacts with water, releasing explosive hydrogen gas.

Propylene Carbonate

Propylene carbonate ($C_3H_6CO_3$) is practically non-toxic to mammals. No data are available concerning its toxicity to other organisms. Propylene carbonate is flammable and slightly soluble in water.

Sulfur Dioxide and Sulfurous Acid

Sulfur dioxide (SO_2), a gas, is toxic to plants, mammals, fish and insects. Concentrations in air of less than 1 ppm have caused toxic reactions in plants.

In mammals, the harmful effects of SO_2 are due to physical damage to the lungs and other moist areas. In contact with water, SO_2 forms sulfurous acid (H_2SO_3) which corrodes the tissue.

The formation of H_2SO_3 is also the mechanism by which SO_2 exerts toxic effects on fish and other aquatic life.

Summary

The lithium-organic electrolyte/SO_2 cell contains several substances that can cause serious environmental problems. Three broad areas of concern are: (1) release of toxic or hazardous compounds to leachate water; (2) release of toxic gases; and (3) fire or explosion hazard. The principal problems to be considered in disposal of the cell are:

(1) Discharged cells tested to date contain measurable quantities of cyanide which is extremely toxic to all forms of life;

(2) Plants or livestock may be harmed by sulfur dioxide, or lithium ion (recommended maximum concentration of Li^+ in irrigation water is 2.5 mg/l - see Appendix A).

(3) Acetonitrile or propylene carbonate could be ignited by heat released during the reaction between metallic lithium and water, or some other heat source, and could cause a fire or explosion.

Table 2.1-1 gives a qualitative rating of the toxicity and hazard of each of the compounds found in the lithium-organic electrolyte/SO_2 battery. The rating is based on a qualitative assessment of the toxicity of the components with respect to the concentrations likely to result from battery disposal.

TABLE 2.1-1

QUALITATIVE TOXICITY AND HAZARD POTENTIAL FOR LITHIUM BATTERY COMPOUNDS

Compound	Toxic to Plants	Toxic to Aquatic Animals	Toxic to Mammals (incl. humans)	Airborne Toxin or Hazard	Handling Hazard
Acetonitrile	u.k.[1]	No	No	No	Yes
CN^-	Yes	Yes	Yes	No	Yes
HCN	Yes	Yes	Yes	Yes	Yes
Li metal	Yes	Yes	Yes	Yes	Yes
Li^+	Yes	Yes	No	No	No
Br^-	u.k.[1]	No	No	No	No
$S_2O_4^=$	u.k.[1]	No	No	No	No
OH^-	Yes	Yes	Yes	No	Yes
Propylene Carbonate	u.k.[1]	u.k.[1]	No	No	Yes
SO_2	Yes	Yes	Yes	Yes	Yes
H_2SO_3	Yes	Yes	Yes	No	Yes

[1]Unknown - Information on toxicity for this group is not in published literature.

B. Disposal Regulations

Although there are no federal or state regulations that refer specifically to disposal of lithium batteries, a number of solid waste disposal laws include provisions that are applicable to battery disposal.

1. Federal Regulations

Federal legislation was examined for regulations pertinent to disposal of lithium batteries. Of the federal legislation, the Solid Waste Disposal Act of 1965, as amended by a series of acts including the recent "Resource Conservation and Recovery Act of 1976", is the most relevant to lithium battery disposal. This comprehensive Act provides for a number of activities, including the development of guidelines for solid waste management; establishment of the Office of Solid Waste within the EPA; authorization for regulating disposal practices; technical assistance to local governments; stimulation of markets for and government procurement of recovered resources; technological and financial assistance to programs demonstrating new resource recovery systems; management directives for hazardous wastes; and development of state or regional solid waste plans.

The latter two subtitles of the Act are most pertinent to disposal of lithium batteries. Subtitle C - Hazardous Waste Management - calls for the identification or listing of hazardous wastes; promulgation of disposal and transportation regulations for these wastes, including provisions for record-keeping, reporting, monitoring, and inspecting disposal facilities; establishment of a permit system for solid waste disposal facilities; and provisions for enforcement of hazardous waste regulations and penalties for violation. Regulations will go into effect by April 22, 1978 (18 months after the enactment of the amendments).

Subtitle D of the Act - State or Regional Waste Plans - calls for establishment of state or regional solid waste disposal plans which must comply with several requirements, including: the phasing out of all open dumps - to be replaced by resource recovery, sanitary landfills, or other environmentally appropriate methods; minimum criteria for sanitary landfills; coordination of state and/or regional efforts; and establishment of State regulation and enforcement powers.

Since Subtitles C and D were only recently enacted as part of the "Resource Conservation and Recovery Act of 1976", little EPA or state action has been taken on them. However, to comply with Subtitle D, serveral states are starting to compile lists of substances which will not be permitted in sanitary or general purpose landfills. Telephone contacts with several state solid waste agencies indicated that these lists will probably include cyanide, pressurized gases, and possibly lithium.

2. State Regulations

State legislation was reviewed for provisions relating to disposal of lithium batteries. While none of the states have regulations specifically aimed at disposal of lithium batteries, at least one regulates disposal of wastes containing cyanide and pressurized gases, and several require that landfill operators obtain special permits before accepting chemical or industrial wastes.

A survey of state legislation revealed that all fifty states have passed legislation providing for promulgation of guidelines or regulations for solid waste disposal. Forty-five have granted enforcement authority to agencies and have prescribed penalties for violation (A state-by-state rundown of legislation is given in Appendix B).

The most stringent solid waste legislation has been enacted by the West Coast states. California has defined several types of landfills and has prescribed the wastes which may be accepted by each type. Wastes containing cyanide or pressurized gas must be disposed of in a secured landfill. The State of Oregon requires sanitary landfill operators to examine wastes and to reject all chemical or industrial materials (including batteries), which must be sent to secured landfills. Washington State, as well as a number of other states throughout the country, is currently preparing a set of criteria listing hazardous wastes and regulating their disposal.

C. Disposal Methods

Available disposal methods have been grouped into five broad categories: landfill; incineration; recovery and reuse; ocean dumping; and other methods. Landfill methods are varied and are used to dispose of most of the solid wastes generated in the United States. In a recent study of solid waste disposal in the battery manufacturing industry,[15] Versar identified five methods currently used to dispose of scrap cells: open dumping; disposal in general purpose landfills; disposal in special purpose landfills; drumming (packing in steel drums) prior to landfilling; and recovery and reuse.

A short description of each of the methods available for the disposal of solid wastes is summarized below, along with Versar's assessment as to their applicability to the disposal of lithium cells. In reviewing each of these methods, it was assumed that the cell would be disposed of "intact" rather than in a crushed or open manner. Uncontrolled crushing of the battery has the potential for creating a hazardous situation at the disposal site due to the chemical nature of the battery.

1. Landfill Methods

Landfills can be divided into five groups:

Open dumps
General purpose landfills
Sanitary landfills
Special purpose landfills and
Secured landfills.

Each of these will be discussed below.

In addition to these options, several modifications are available to increase the environmental security of solid waste disposal. These modifications include drumming, encapsulation and chemical fixation and will be discussed under the sub-heading "modifications".

Open Dumping

Open dumping of solid wastes into dumps, gravel pits, and other uncontrolled areas is still a prevalent disposal practice. This disposal

method has been widely used for many years because of its convenience and low cost, but is environmentally dangerous because of air pollution, leachate, runoff, pathogenic dissemination, and fire potential.

The Resource Conservation Recovery Act of 1976, as described in Section 2.2, prohibits open dumping and for this reason, the open dumping of any quantity of lithium cells is environmentally unacceptable.

General Purpose Landfills

General purpose landfills are characterized by their acceptance of a wide variety of wastes (e.g., construction debris, paper, and other non- or slowly biodegradable materials), and by the usual absence of special containment, monitoring, documentation and leachate treatment provisions for hazardous wastes.

At this point in time, Versar considers the general purpose landfill to be unacceptable for the disposal of lithium cells. This is based on the fact that most of these landfills are operated in an uncontrolled manner, in that the wastes are usually not segregated, the operator is typically not concerned with the location of various waste material, and it is very uncommon for these landfills to monitor and measure leachate. Because of the flammable nature of lithium cells and the levels of cyanide detected in discharged cells tested to date, the uncontrolled placement of cells in a general purpose landfill is too great an environmental risk. Even if cyanide were not present in the discharged cells, the fact that the cell contains pressurized gas and flammable materials is likely to exclude its consideration as a waste accepted in a general purpose landfill.

Sanitary Landfill

Sanitary landfills are basically general purpose landfills which accept biodegradable wastes. Such wastes as domestic and commercial garbage, sewage sludge, and other rapidly degradable material are routinely placed in sanitary landfills. Most major municipalities operate a sanitary landfill for the receipt of curb-side collected garbage and other sanitary wastes. Although state laws are variable, most require the operator to compact and cover the wastes in a prescribed manner. The leachate from sanitary landfills can cause water quality problems (both surface and subsurface) due to the heavy organic load (e.g., high biochemical oxygen demand) that results from the decaying waste. The generation of methane gas, due to anaerobic action in these wastes, is also a potential hazard at the landfill site.

Based on data generated to date, it is Versar's opinion that sanitary landfilling may be unacceptable for disposal of lithium cells. However, further documentation of the cyanide levels and quantities of batteries for disposal under actual field conditions need to be assessed before a final recommendation can be made. In addition, low permeability soils containing clay and silt may to some degree adsorb cyanide and remove it from leachate produced by the lithium cells. This would effectively reduce the potential toxid effects of the cyanide in the leachate.

However, disposal of the cells may be judged unacceptable for sanitary landfill purposes by Federal or State regulatory agencies. Most sanitary landfills do not exercise control over the material received, do not practice waste segregation, and do not monitor or make provisions for controlling leachate. The biological action that occurs in a sanitary landfill could also present problems to the disposal of lithium cells. Biodegradation may liberate cyanide ion from the acetonitrile electrolyte.[4]

Special Purpose Landfill

Special purpose landfills accept only a specific material or class of wastes. Except for this fact, they are usually operated like a general purpose landfill - without special containment, monitoring or leachate control. Versar's recent studies of solid wastes in the battery industry[15] indicated that primary battery manufacturers rely heavily upon the special purpose landfill for disposal of scrap cells. The cells are often crushed before disposal so that they cannot be collected and sold as new batteries. In most cases these special purpose landfills are operated without proper control of leachate which can result in ground water contamination.

Disposal of small quantities of lithium cells in a special purpose landfill would involve segregating the cells themselves or all waste generated in a field situation which would include the lithium cells.

However, disposal of lithium cells in a landfill dedicated to lithium cells may not mitigate the environmental effects that will occur. Potential contamination of ground water still exists due to the presence of cyanide, SO_2 and lithium in the discharged cell. Disposal of toxic material in a landfill which does not have leachate control may still produce adverse environmental effects.

Secured Landfill

The definition and criteria for a secured landfill include:[15]

(a) The composition and volume of each waste is known and approved for site disposal by pertinent regulatory agencies;

(b) The site should be geologically and hydrologically approved for hazardous or toxic wastes. Included in the criteria would be a soil or soil/liner with a permeability of less than 10^{-8} cm per sec permeability of (soils tested in this program range from 10^{-2} to 10^{-6} cm/sec), a water table below the lowest level of the landfill, and adequate provision for diversion and control of surface water:

(c) Monitoring wells are provided;

(d) Leachate control and treatment;

(e) Records of burial coordinates to avoid any chemical interactions; and

(f) Registration of the site for a permanent record.

A number of landfills which meet the physical requirements (if not all the regulatory criteria) are located aroung the country. California has a number of Class 1 impermeable landfills which accept extremely hazardous materials. Texas has similar sites. A number of low level radioactive waste landfill sites accept industrial hazardous wastes. In addition to the radioactive waste sites, various other privately owned secured landfills also accept hazardous wastes. At the present time, secured landfills are scattered and are not fully utilized. Part of the lack of utilization stems from the fact that the majority of the sites are in isolated western areas away from industrial centers. Another reason for the lack of utilization is the high cost as compared to other available disposal methods.

Low permeability soils exist in some areas of the country. If impermeable soil is not available, then concrete, asphalt, plastic and other liners and covers are available to accomplish similar containment and isolation of wastes.

In light of the data available at this time, it is believed that the large and small scale disposal of lithium cells can best be accomplished in a

secured landfill that meets the definitions described above. This includes provisions for geological location of waste placement, monitoring wells, and leachate control. States which operate secured or hazardous material landfills have stringent requirements on the disposer to identify and quantify all materials to be disposed, including toxic materials.

Modifications

Several modifications are available to enhance the environmental protection afforded by landfill disposal methods. Three of these modifications involve isolating the wastes; the fourth involves chemical treatment of the toxic components. The modifications are discussed below.

Drumming-Steel drums, alone or with plastic liners, provide some short-term containment, and also are a convenient storage and transportation mode for relatively small quantities of waste (The Department of Transportation regulations for shipment of lithium-organic electrolyte-SO_2 cells limit gross weight of container and cells to 75 pounds). There are two problems associated with drumming: (1) breaking during compaction; and (2) eventual decay of the steel drums. Therefore, unless disposed of in an appropriate landfill site, release to the environment is inevitable.

Encapsulation-Relatively impervious materials such as asphalt or clay can be used to cover wastes (capping) to retard vertical percolation of water. Although this method tends to reduce the flow of water through the wastes, horizontal movements are unaffected. Thus the leachate that does come in contact with the wastes will contain greater concentrations of soluble materials.

Complete encapsulation is used to isolate (or at least restrict contact with) wastes from ground water. Encapsulation may be done *in situ* by lining the disposal site with clay or asphalt and capping the site after depositing the wastes, or may be done prior to deposition by encapsulating the wastes in concrete or plastic. Like capping, any leachate that does reach the wastes will pick up high concentrations of soluble materials. A further consideration is that organics from asphalt and plasticizers from plastic may create leachate problems of their own.

Unless provisions are made for isolation from ground and surface water, leachate control and treatment, and separation from other wastes, encapsulation alone is likely not acceptable for lithium cell disposal. Although encapsulation approximates secured landfill conditions, the ability of various encapsulating materials to control soluble materials in the leachate is unknown. Further study is needed to establish the capacity of encapsulation to contain leachate from the battery.

Chemical fixation-Hazardous sludges may be treated either on-site or in collection areas by mixing them with inorganic chemicals and catalysts to set up the entire mass into solid structures with low leachability and good land storage or landfill characteristics. There are a number of such processes which produce solids ranging from crumbly soil-like materials to concrete to ceramic slags. There has been no reported instance of chemical fixation being used on battery industry wastes.

2. Incineration

Incineration may be used to dispose of combustible solid wastes. Although incineration reduces or eliminates the volume of solid wastes, it may change a solid waste problem to an air pollution problem. Incineration requires the utilization of sophisticated burn control equipment to ensure maximum combustion and to prevent formation of incompletely oxidized compounds such as NO_x and SO_x.

Incineration is judged to be impractical for lithium cell disposal because of the following problems:

1. Materials containing more than 25 ppm of heavy metals are generally unacceptable for incineration. Nickel-plating of the steel case of the cell presents a problem here. The cells would have to be dismantled prior to incineration.
2. Volatilization of lithium;
3. Release of sulfur dioxide and hydrogen cyanide;
4. Safety problem inherent in opening of the cells, i.e., when cut or broken the cells may burn or explode.

3. Recovery and Reuse

Recovery and reuse is generally the most environmentally acceptable method of disposing of wastes in that it reduces pollution not only from the 'wastes', but by avoiding the necessity for continued extraction of the resource from its natural source. Many hazardous wastes from the battery industry contain valuable materials. Lead, silver, mercury, cadmium and other heavy metals are sometimes recovered economically rather than land disposed. However, when these metals are minor constituents of the waste, it is not economical to follow the recovery or reuse approach. The major factor standing in the way of recovery of most of the metals going to landfill from batteries is the disassembly of cells to separate the recoverable and non-recoverable components.

There are also private contractors who specialize in hazardous waste reclamation. In the battery industry this situation is encountered with a number of batteries including mercury cells, silver cells, and cadmium cells.

Although the economic feasibility of recovering heavy metals from batteries has been demonstrated, there is no evidence that economic recovery of materials from lithium cells is possible. Also, the hazard of opening the cells is a severe problem in recovery of materials.

In summary, although recovery or reuse of the lithium cell is environmentally desirable, economic and safety considerations appear to make this approach impractical at this time.

4. Ocean Dumping

Currently a few hazardous wastes generated by industry are disposed of by ocean barging. Most of these wastes will in the future be destined for land disposal. This method is not presently used by the batteries industries, and because of possible environmental damage is not a viable choice for future disposal. The EPA requires that a permit be obtained for all ocean dumping operations, and it is a current policy that no new permits are being issued. For this reason, ocean dumping is not a viable alternative.

5. Disposal Ponds or Lagoons

Disposal ponds or lagoons are a frequently used approach to some types of hazardous waste disposal. However, there are some serious drawbacks.

(a) The pond must prevent contamination of both surface and ground water. In almost all areas this means a lined pond. Liners include clay, plastic, concrete and epoxy, some of which are relatively expensive.

(b) Except in very dry climates, ponds without seepage or discharge will overflow from rainfall accumulation.

(c) Ponds are prone to be "flushed out" with massive rainfall. It is sometimes difficult and expensive to provide flood and runoff protection.

(d) Volatile substances such as hydrogen cyanide and sulfur dioxide can escape unhindered into the atmosphere.

There are also some advantages. It is easier to monitor and treat the pond water than leachate water from landfills. Also, aerobic decomposition of oxidizable wastes may proceed more readily due to the unimpeded diffusion of oxygen.

Based on the available data, we think that disposal ponds could be an acceptable disposal method for lithium cells provided that leachate and surface runoff can be controlled, monitored, and treated.

6. Deep Well Injection

Deep welling is a specialized form of land disposal of hazardous wastes. It is normally restricted to liquids only, since suspended solids or sludges tend to clog the porous rock shale or sand structure into which the injection occurs. Another restriction is that a suitable aquifer must be found in which hazardous wastes can be permanently contained, and will not contaminate ground water supplies. Furthermore, drilling and high pressure pumping equipment must be used to inject the liquids.

Although intact lithium cells could not be disposed of by deep well injection, Versar examined the possibility of disposing of the liquid components of the cell via this method. Because of the hazard involved in removing the liquids, the possibility of fire or explosion during injection,

the problem of disposing of solid residues after removing the liquids, and the expense of this operation, deep well injection is not a viable method for disposal of lithium battery wastes.

7. Municipal Sewers

Many industries dispose of soluble substances by discharging them to municipal sewers for treatment at sewage treatment plants. Although all of the liquid or dissolved substances in the lithium battery are extremely soluble in water, with the exception of propylene carbonate (which is slightly soluble), discharge of these substances into municipal sewers was deemed unacceptable because:

(a) Most sewage treatment plants are unprepared and unwilling to accept wastes containing cyanide and sulfur dioxide;

(b) Removing the liquid components of the battery could be extremely hazardous, since any metallic lithium remaining in the battery could react violently with water, possibly causing a fire or explosion; and

(c) Solid residues would still require disposal.

D. Laboratory Testing

A laboratory testing program was designed to evaluate the mobility and leachability of specific cell components in soil and water. The program was divided into three phases, which are described in detail below. The purpose of the laboratory testing program was as follows:

- To determine the identity of the chemical species formed when the cell components are exposed to water, and the solubility and variation with time of specific cell components from both live and discharged cells in distilled water. (Phase 1)
- To assess the amount of component adsorption by three soil types of varying mineralogy and grain size in a slurry mixture with live and discharged battery solutions (Phase 2), and
- To determine the mobility and adsorption of cell components in representative soil columns of varying mineralogy and grain size under saturated soil conditions (Phase 3 and Leachate Tests)

1. Phase I Tests

Methods and Materials

The materials used in this phase included the following:

five - 5 gallon stainless steel vessels
liquid nitrogen
distilled water
mechanical hack saw and battery holding jig
eight cell dischargers*

The method used in this phase involved the following steps:

a. Four cells were tested for their amperage and voltage. Since both live and discharged cells were to be compared, two cells were discharged for 72 hours with a line resistance of five ohms.

* cell discharger - "D" cell holder with two resistors, rated at 10 ohms, 10 watts, in parallel between cell holder poles.

b. Prior to opening, all cells were frozen in liquid nitrogen for 30 minutes to reduce the internal pressure from about three atmospheres to about one atmosphere. This was done principally to reduce the amount of SO_2 vaporization during opening.

c. Two live and two discharged cells were cut in half longitudinally using a mechanical saw in a closed fume hood.

d. Upon opening, the cells were dropped into separate stainless steel beakers containing five liters of distilled water. Time from opening to submergence in water was generally less than 15 seconds to 30 seconds at the maximum.

e. The beakers containing live and discharged cells were segregated within the fume hood to minimize any transfer of volatile constituents from one beaker to another. A control was set up with distilled water alone.

f. Cell reaction in water was observed until effervescence stopped. Length of time and rate of bubbling were recorded.

g. Samples for analysis were taken in 200 ml aliquots at 4, 24, 72, 144 hours after placement in stainless steel vessels. The 200 ml sample was analyzed immediately for pH, conductivity and temperature. Samples were then split into two 100 ml samples, one for lithium and sulfite analyses, one for cyanide analysis. Samples were filtered using a 0.45 micron micropore glass filter under suction and preserved according to EPA approved methods (lithium and sulfite sample stored at 4°C; cyanide sample adjusted to pH 12 with 10% NaOH). (See Appendix C for specific methods).

h. Each test was run in duplicate i.e. two discharged cells and two live cells.

To assure that cyanide results were reflective of actual cyanide and not due to acetonitrile dissociation cuased by analytical method, an acetonitrile control was analyzed for cyanide. From a one to 1,000 dilution of acetonitrile (0.787 grams acetonitrile) a cyanide concentration of 8 mg/l was detected. From data presented, the ratio of cyanide to acetonitrile is one percent. This compares to a ten percent ratio computed from Phase I cyanide levels. (1.7 grams acetonitrile/liter compared to 160 mg/l cyanide detected).

Another indication that cyanide concentration is a result of cell component alteration is that the two live cells showed cyanide levels greatly below that of discharged cells. This would not be the case if the actual analysis procedure led to acetonitrile dissociation. Based on these two facts it was concluded that cyanide results reflect actual cyanide levels due to acetonitrile dissociation in discharged cells.

Phase I Results

pH

Both discharged cell solutions showed an arithmetic decrease of pH over the entire test period as shown in Figure 2.4-1. Discharged cell I solution decreased 1.3 pH units from 11.9 at 4 hours to 10.6 at 144 hours. Discharged cell II solution decreased from 11.6 at 4 hours to 8.9 at 144 hours; a change of 2.7 pH units. Live cell I solution showed a geometric increase from 6.4 at 4 hours to 10.3 at 144 hours, or an increase of 3.9 pH units. Live cell II pH trend resembled a discharged cell decreasing by 0.8 pH units from 11.2 to 10.4 over the test period. Flaming occurred when the live cell II was cut open, and may have resulted in a pH condition atypical for a live cell.

Conductivity

As shown in Figure 2.4-2, discharged cell I and II solutions decreased in conductivity through 24 hours, from 6400 to 5200 μmhos/cm and 5100 to 3200 μmhos/cm, respectively. From 24 hours to 144 hours both discharged cell solutions increased to about the same levels, 5500 and 5600 μmhos/cm.

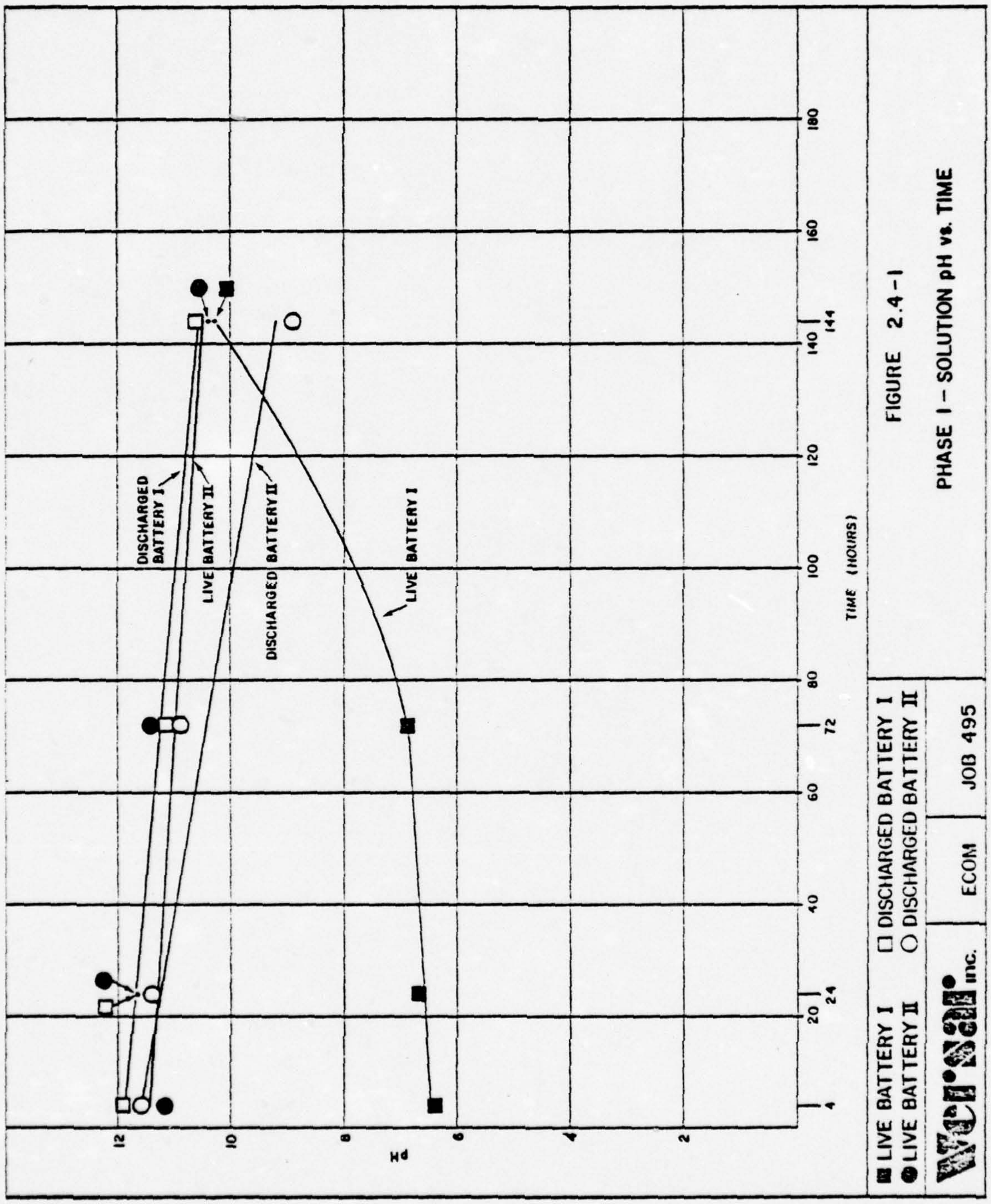


FIGURE 2.4-1

PHASE I - SOLUTION pH vs. TIME

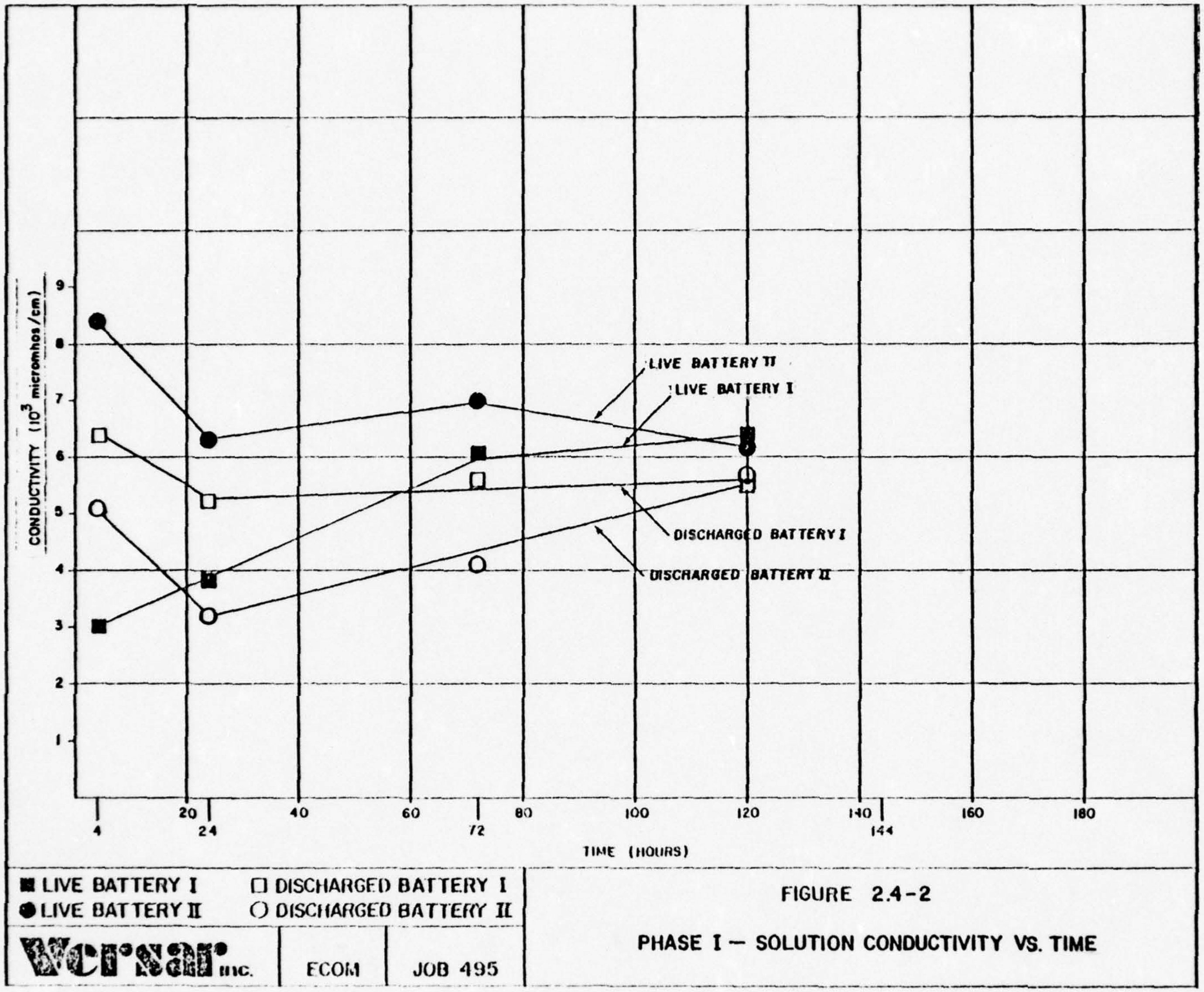


FIGURE 2.4-2

PHASE I — SOLUTION CONDUCTIVITY VS. TIME

Live battery I solution increased in conductivity from 3000 to 6400 µmhos/cm over the test period. The live cell II solution trend resembled the discharged cell solution, showing a decrease in conductance from an initial high of 8400 to 6300 µmhos/cm at 24 hours. From 24 hours to 72 hours, conductivity increased from 6300 to 7000 µmhos/cm, followed by a decrease from 7000 to 6200 µmhos/cm from 72 to 144 hours. However, both live cell solutions at 6400 and 6200 µmhos/cm are considered similar being 700 to 800 µmhos/cm higher than the solutions.

Sulfite

As shown in Figure 2.4-3, discharged cell I solution fluctuated over the test period with an initial and final sulfite concentration of 1030 mg/l. Discharged cell II solution increased steadily from 360 to 2100 mg/l through 144 hours. Live cell I solution showed only a small gradually increase from 1730 mg/l at 4 hours to 2350 mg/l at 144 hours.

Live cell II solution increased geometrically from 1980 mg/l at 4 hours to 5520 mg/l at 72 hours, and remained at a level about two times that of the live cell I solution through 144 hours.

Lithium

As shown in Figure 2.4-4, both discharged cell I and II solutions displayed geometric increases from 353 mg/l and 339 mg/l, respectively, at 4 hours to 1076 mg/l and 891 mg/l respectively, at 144 hours.

Both live cell solutions I and II increased in lithium concentration at a linear rate from 475 and 658 mg/l at 4 hours to similar concentrations of 798 and 791 mg/l, respectively, at 144 hours.

Cyanide

As shown in Figure 2.4-5, cyanide concentrations for both discharged cell I and II showed increased through 24 hours; discharged cell I solution increased from 34 mg/l at 4 hours to 41 mg/l at 24 hours then decreased to 26 mg/l at 144 hours.

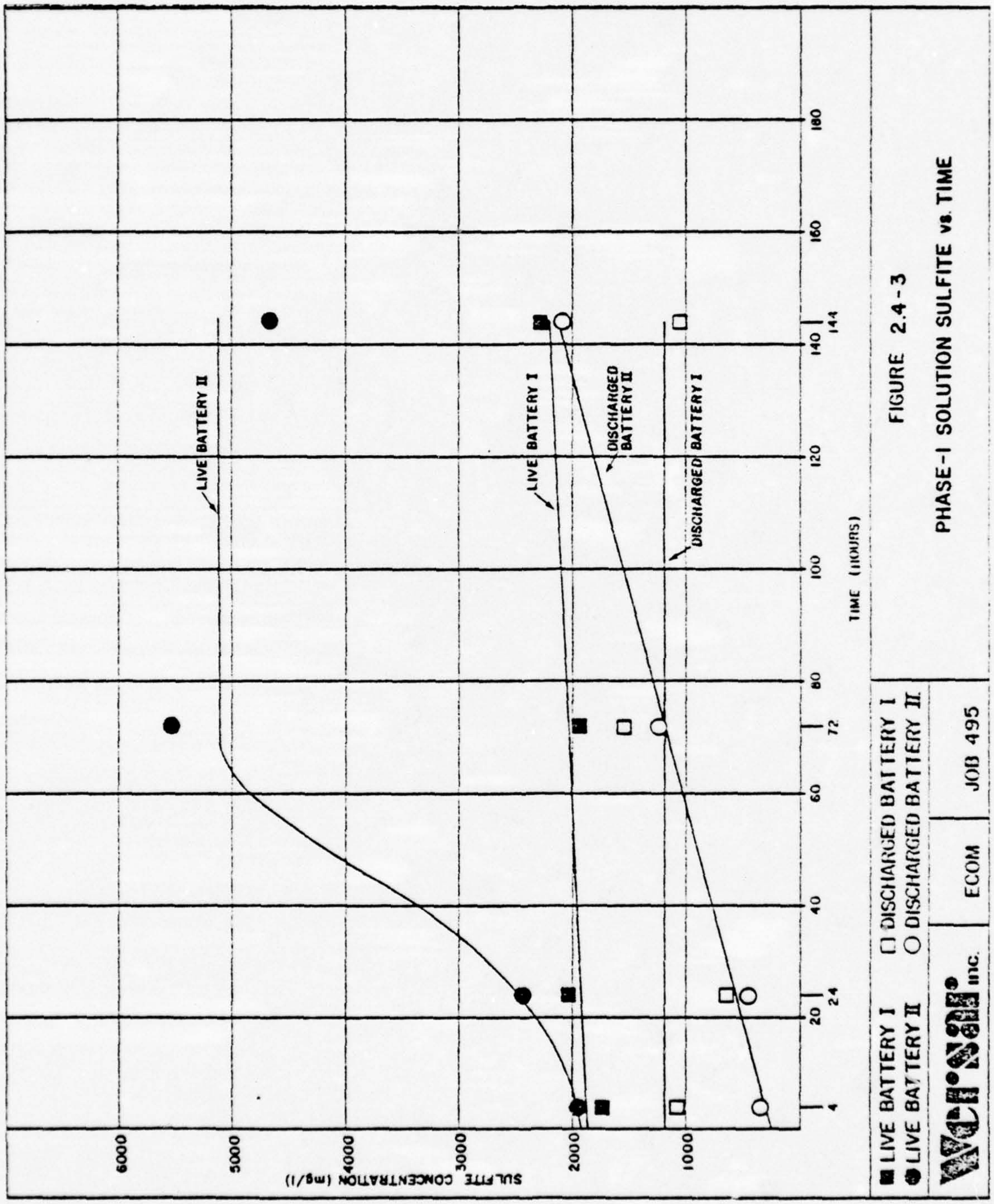
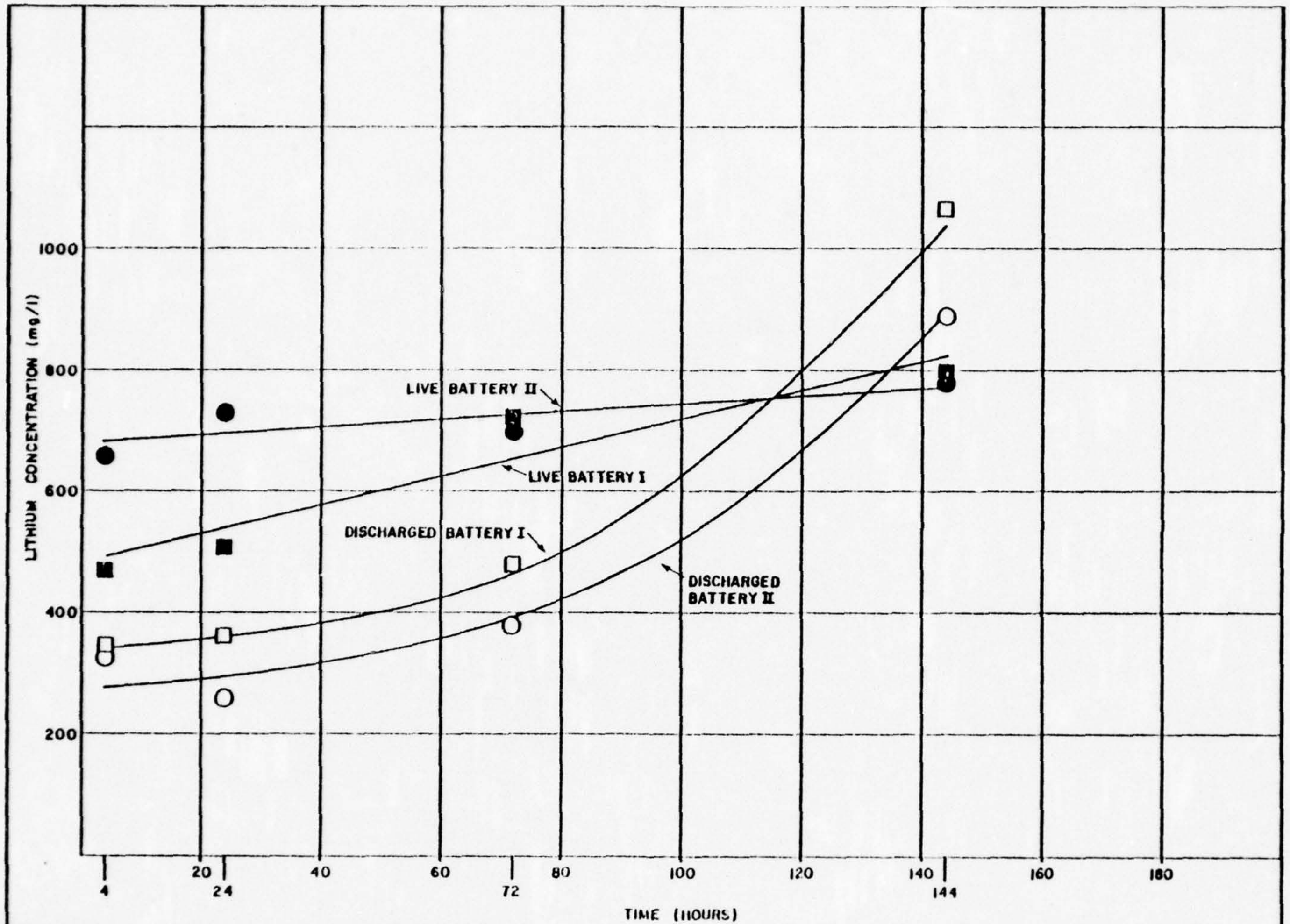


FIGURE 2.4-3

PHASE-I SOLUTION SULFITE vs. TIME



■ LIVE BATTERY I
● LIVE BATTERY II
□ DISCHARGED BATTERY I
○ DISCHARGED BATTERY II

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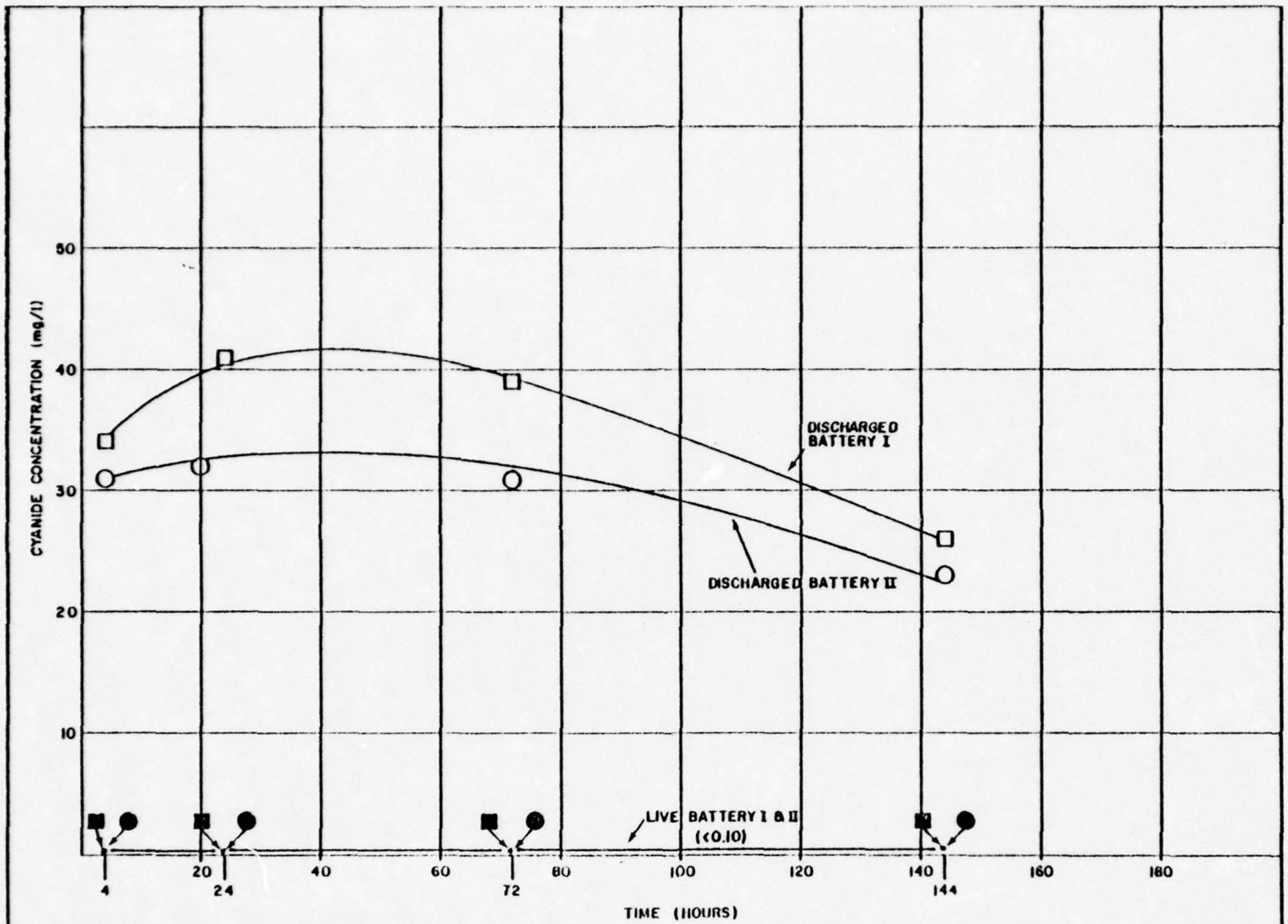
FIGURE 2.4-4

PHASE I-SOLUTION LITHIUM vs. TIME



■ LIVE BATTERY I	□ DISCHARGED BATTERY I	
● LIVE BATTERY II	○ DISCHARGED BATTERY II	
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FIGURE 2.4-5

PHASE I-SOLUTION CYANIDE vs. TIME

Discharged cell II solution cyanide concentrations were similar in trend to the discharged cell I solution. After increasing from 31 mg/l at 4 hours to 32 mg/l at 24 hours, the cyanide decreased to 23 mg/l at 144 hours. Both discharged cells then showed about 25 percent decrease in cyanide concentration over 144 hours.

Live cell I and II solutions were consistently below 0.10 mg/l in cyanide concentration.

Phase I Summary

Some similarities and differences were apparent between live and discharged cell component concentrations at the end of 144 hours. Cyanide concentrations were 23 and 26 mg/l in the discharged cell solutions whereas they were less than 0.1 mg/l for both live cell solutions. Final lithium concentrations in the discharged cell varied, but were higher than the live cell solutions by about 100 and 275 mg/l. Conductivities in the live cell solutions were about 850 µmhos/cm, about 15 percent higher than in the discharged cell solutions. The pH ranges were alkaline for all solutions ranging from 8.9 to 10.4. There was as much variation in sulfite levels in the two live as in the two discharged cell solutions, all ranging from 1080 to 5520 mg/l.

2. Phase II Tests

Methods and Materials

The following materials were utilized in this phase:

Nine - 1 liter Erlenmeyer Flasks
1500 grams (3 x 500 gram portions) each:
- Mattapeake Silty Loam *
- Lakeland Sandy Loam *
- Hagerstown Silty Clay Loam *

2250 milliliters (3 x 750 ml portions) each of
- A live cell Solution**
- A Discharged Cell Solution**

Shaker Equipment

** Live and discharged cell solutions were obtained from preliminary Phase I efforts and had been refrigerated for two weeks prior to Phase II startup. Comparisons between Phase I & II results presented in this text should be made in this light.

* See Appendix Table C-14 for characteristics of soils.

The method employed in this phase involved the following steps:

a. Filtered live and discharged battery solutions obtained from preliminary Phase I efforts were diluted 1:3 with distilled water. A 750 ml aliquot of each diluted solution was mixed with 500 grams of three different soil types. Control experiments were set up with the same three soil types using distilled water.

b. The six slurries were shaken at 120 cycles/min. over the entire test period. Controls were thoroughly shaken four times per day for the test duration. The shaker was turned off 30 minutes prior to sampling, to allow the suspended solids to settle.

c. One 100 ml sample was taken from each decanted solution (referred to subsequently as simply decant) at 4, 24, 72 and 148 hours after test initiation. Conductivity, pH and temperature measurements were made on these 100 ml samples. The 100 ml samples were filtered and split into two 50 ml portions. One of the 50 ml samples was held at 4°C for lithium and sulfite analyses. The other 50 ml sample for cyanide analysis was adjusted to pH 12 with 10% NaOH and held at 4°C.

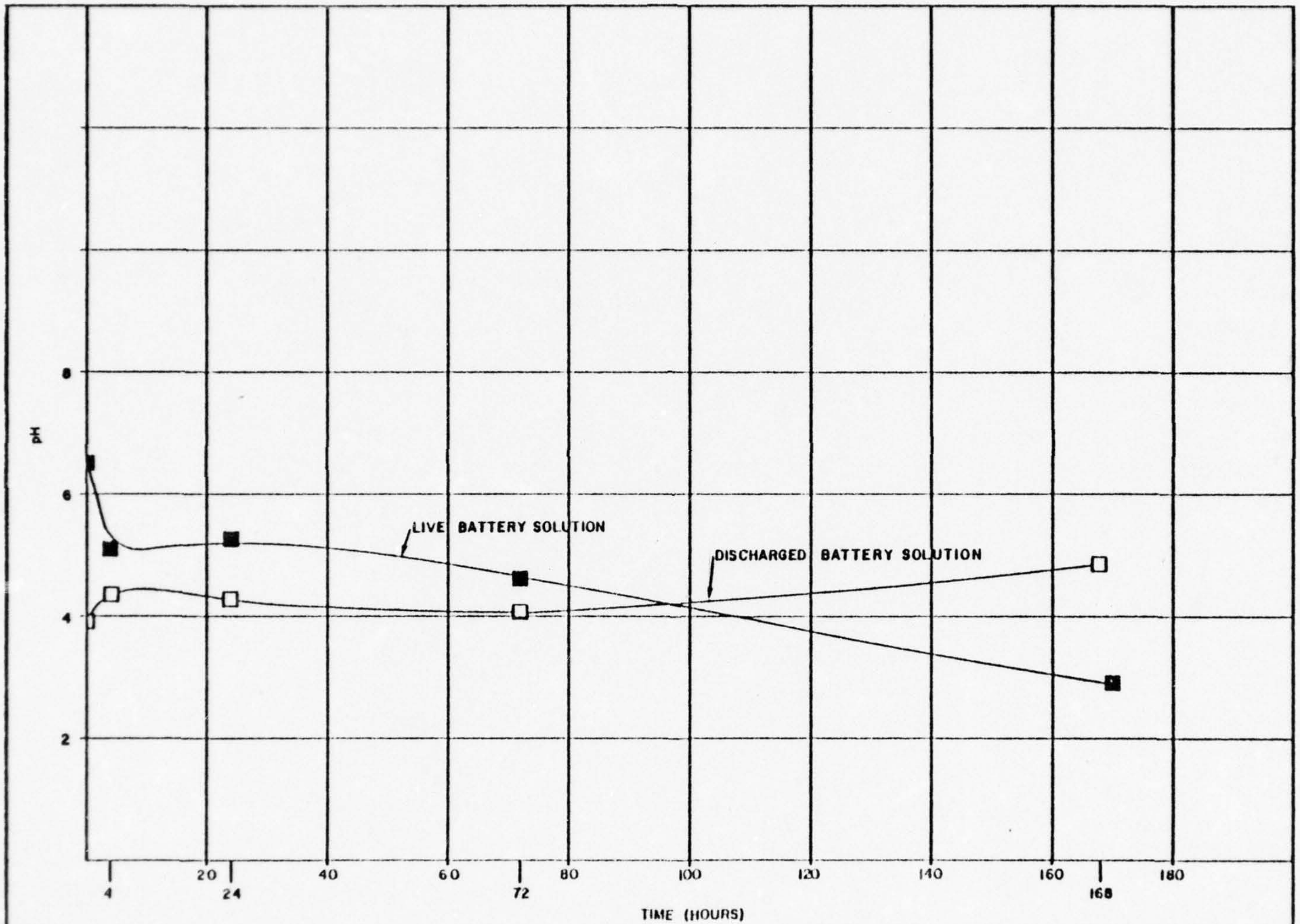
Phase II - Results

pH

a. As shown in Figure 2.4-6, Mattapeake Silty Loam decant, the discharged cells increased slightly in pH in the first four (4) hours from 3.95 to 4.30 followed by a slight increasing trend to a pH of 4.75 at 168 hours.

Live cell decant showed a pH decrease from an initial of 6.5 to 5.1 after 4 hours, and continued to decrease to a final pH of 2.91.

Notes: 1. The Lakeland Spent Slurry was lost due to breakage after 72 hours.
2. No sulfite results are included because of the very low concentrations reported for the solution used.



■ LIVE BATTERY SOLUTION
□ DISCHARGED BATTERY SOLUTION

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FIGURE 2.4-6

PHASE 2–MATTAPEAKE–pH vs. SHAKE TIME

b. Lakeland Sandy Loam.

As shown in Figure 2.4-7, the pH of the discharged cell decant increased for the first 4 hours from 4.0 to 4.3, and decreased at a consistent rate to 4.1 at 74 hours.

The pH of the live cell decant paralled the trend exhibited by the discharged cell decant for the first 72 hours. After a pH decrease in the first 4 hours from 6.5 to 5.7 the pH gradually decreased to 5.3 at 168 hours.

c. Hagerstown Silty Clay.

As shown in Figure 2.4-8, both live and discharge decant 2 displayed similar trends over the test period. Discharged cell decant increased from an initial pH of 4.0 to 5.7 in the first four hours, decreased to 5.5 at 72 hours and increased once again to 6.7 at 108 hours. The live cell decant increased in pH from 6.5 to 6.7 in the first four hours, decreased to 5.7 at 72 hours and increased to 6.6 at 168 hours.

d. Controls.

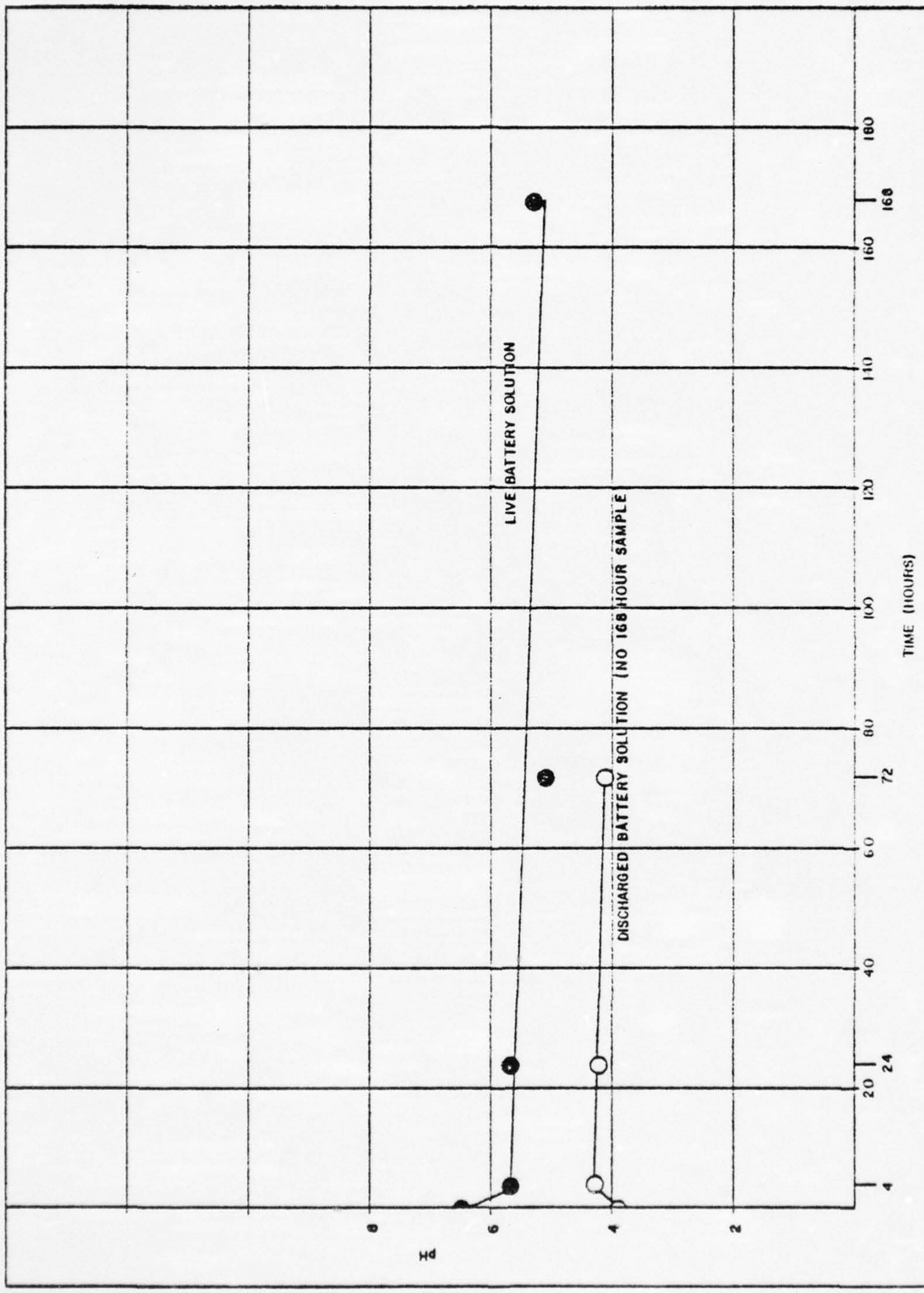
The control decant for Mattapeake soil type had an average pH of 4.5 based on determinations at 24 and 72 hours.

Lakeland control pH averaged 4.6, and Hagerstown control pH average was higher at 6.0. The greatest control variance was 0.2 pH units with the Mattapeake control.

Conductivity

a. Mattapeake Silty Loam.

As shown in Figure 2.4-9, the conductivity of the discharged cell decant decreased from an initial 5900 μmhos/cm to 1980 μmhos/cm in the first four hours. From 4 to 24 hours little change in conductivity occurred. An abrupt increase occurred from 24 to 72 hours changing from 1840 to 2870 μmhos/cm, followed by a slight increase to 3400 μmhos/cm at 168 hours.



● LIVE BATTERY SOLUTION
○ DISCHARGED BATTERY SOLUTION

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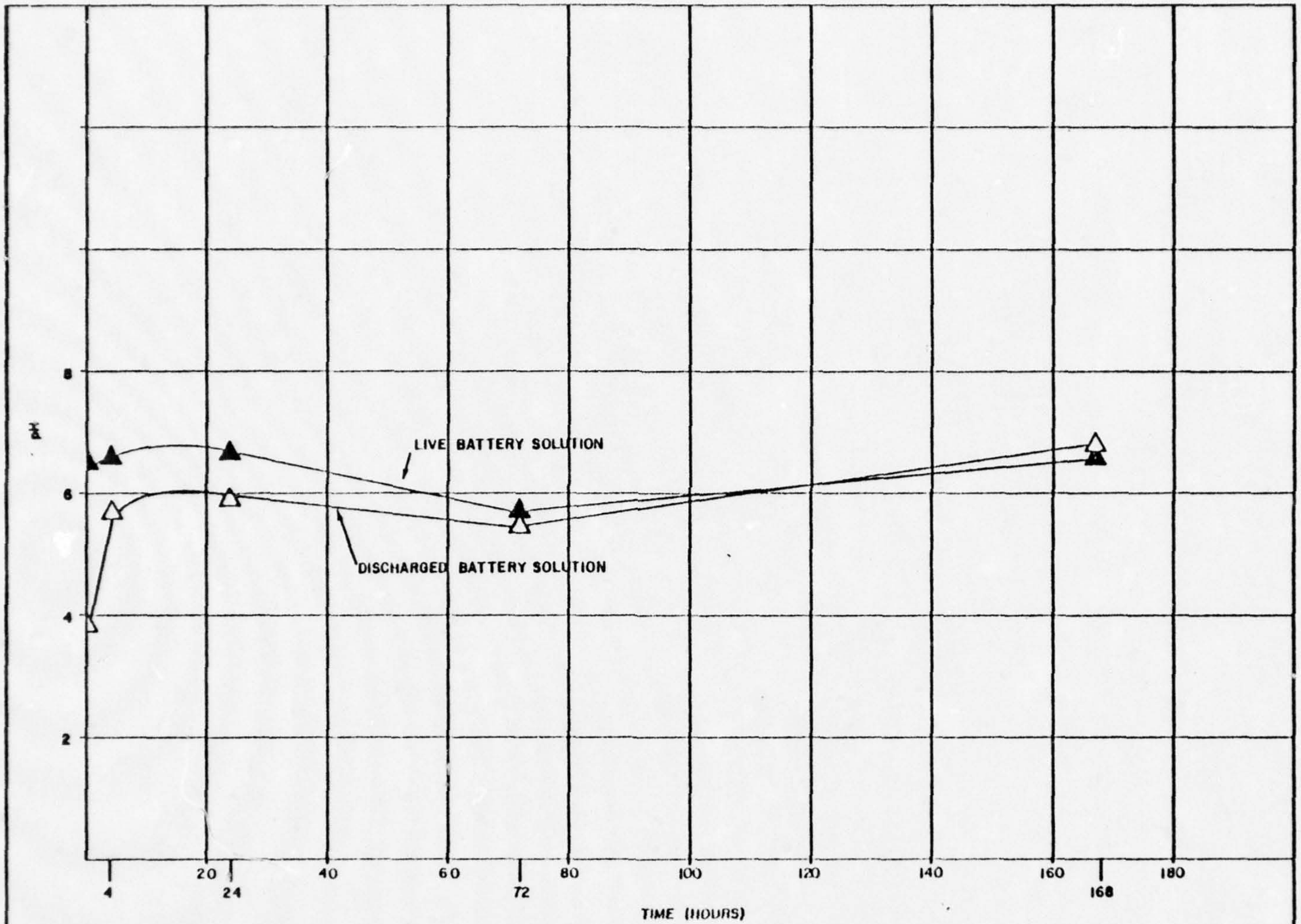
FIGURE 2.4-7

PHASE 2-LAKELAND-pH vs. SHAKE TIME



▲ LIVE BATTERY SOLUTION

△ DISCHARGED BATTERY SOLUTION

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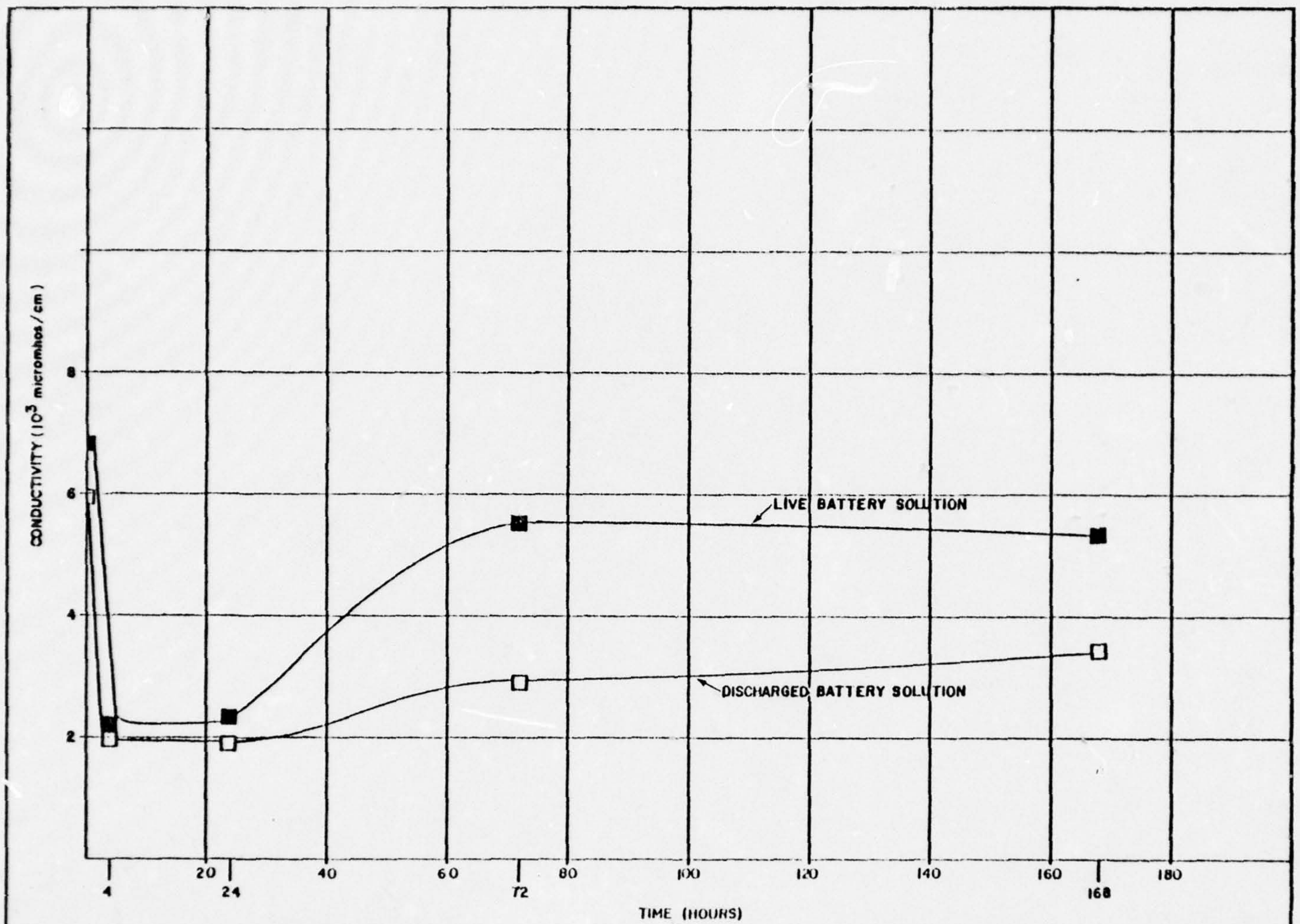
FIGURE 2.4-8

PHASE 2-HAGERSTOWN-pH vs. SHAKE TIME



■ LIVE BATTERY SOLUTION
□ DISCHARGED BATTERY SOLUTION

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FIGURE 2.4-9

PHASE 2 - MATTAPEAKE - CONDUCTIVITY vs. SHAKE TIME

The live cell decant conductivity followed a similar pattern, dropping from an initial reading of 6800 μmhos/cm to 2010 μmhos/cm in the first four hours. From 4 to 24 hours conductivity was stable, but increased from 2240 to 5500 μmhos/cm from 24 to 72 hours. A slight decrease in conductivity was observed for the duration of the test to 5300 μmhos/cm at 168 hours.

b. Lakeland Sandy Loam.

As shown in Figure 2.4-10, a decrease in conductivity was observed for both live and discharged cell decant with changes from 6800 to 2350 μmhos/cm and 5900 to 2200 μmhos/cm respectively for the first 4 hours.

In the case of the discharged cell decant a period of stabilization occurred from 4 to 24 hours, and then increased at a linear rate from 2230 μmhos/cm at 24 hours to 3230 μmhos/cm at 72 hours.

The live cell decant showed a consistent linear increase from 2350 μmhos/cm at 8 hours to 6100 μmhos/cm at 168 hours.

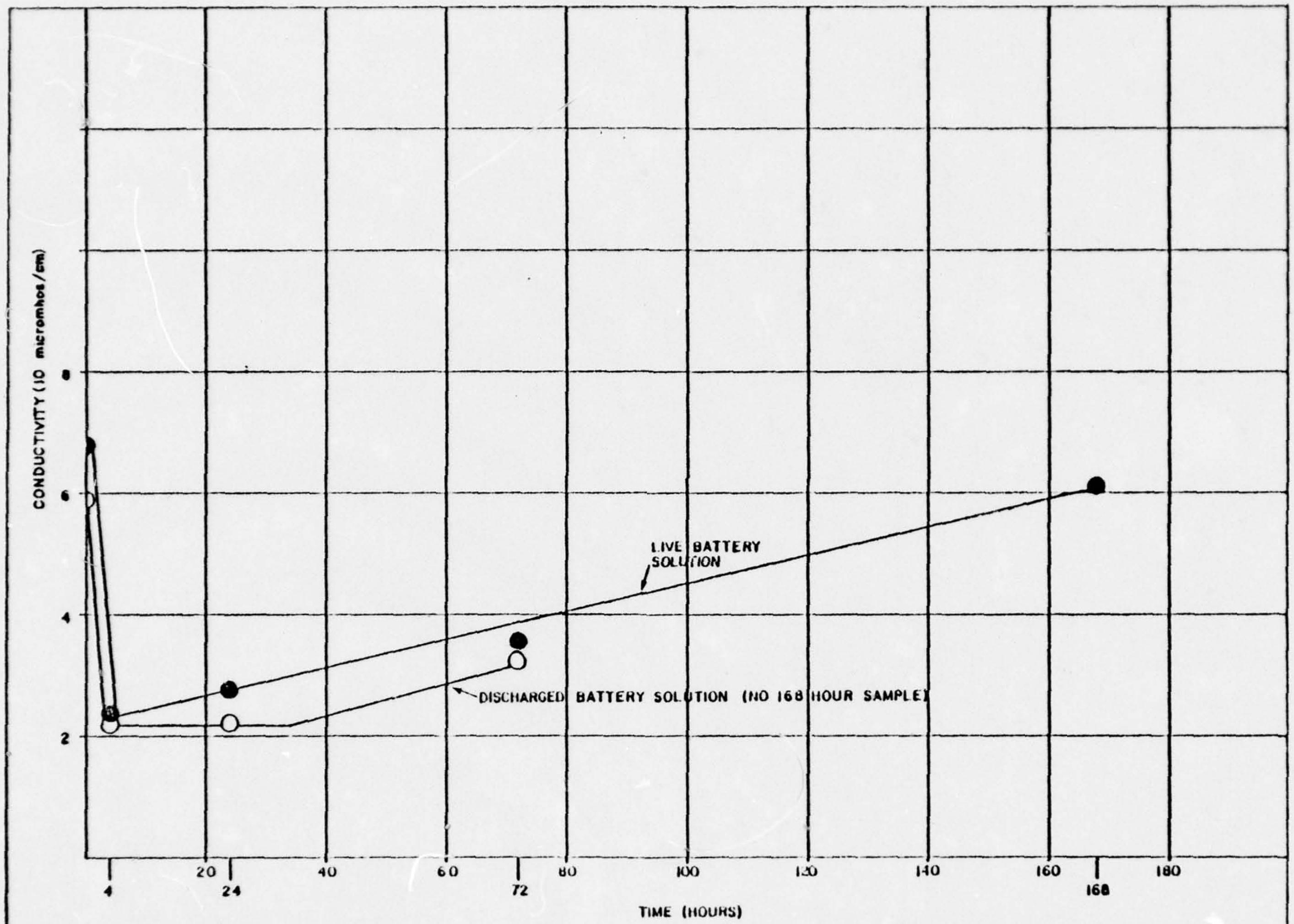
c. Hagerstown Silty Clay.

As shown in Figure 2.4-11, the live and discharged cell decants exhibited similar trends in conductivity. Following an initial decrease in conductivity from about 2100 to 2040 μmhos/cm in the first 4 hours, there was a period of stabilization to 24 hours. Subsequently the conductivity increased at a linear rate from lows about 2100 to 4300 and 4700 μmhos/cm at 168 hours for the discharged and live decants respectively.

d. Controls.

Conductivity of Mattapeake control averaged 127.5 μmhos/cm which is less than ten percent of the lowest conductivity reading of 1840 μmhos/cm for Mattapeake discharged at 24 hours.

Lakeland control conductivity averaged 271.5, 15 percent of the lowest reading for Lakeland discharged at 4 hours (2200 μmhos/cm).



● LIVE BATTERY SOLUTION
○ DISCHARGED BATTERY SOLUTION

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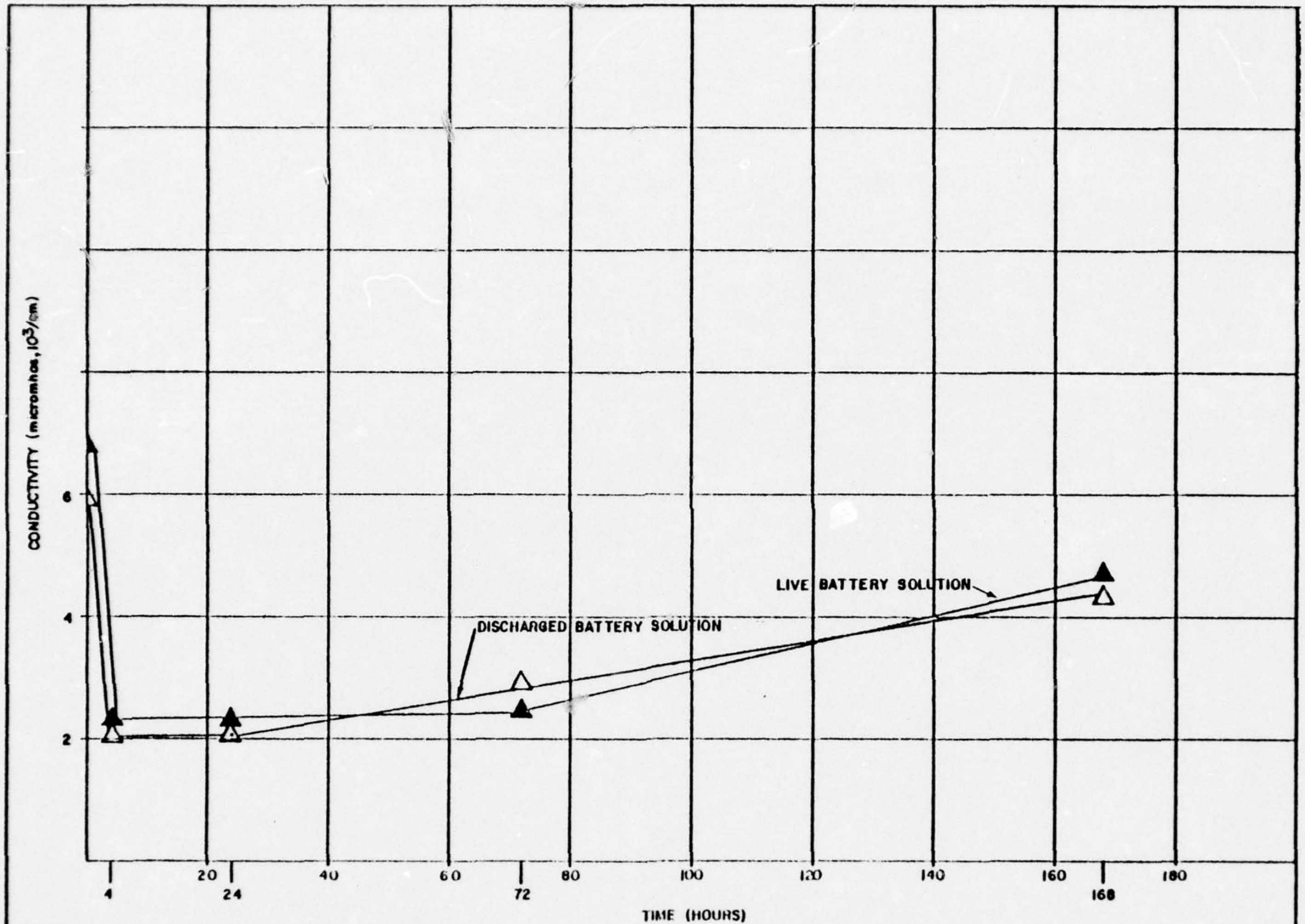
FIGURE 24-10

PHASE 2-LAKELAND-CONDUCTIVITY vs. SHAKE TIME



▲ LIVE BATTERY SOLUTION
△ DISCHARGED BATTERY SOLUTION

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FIGURE 2A-11

PHASE 2-HAGERSTOWN-CONDUCTIVITY vs. SHAKE TIME

Hagerstown control conductivity averaged 205.5 μmhos/cm which is ten percent of the lowest reading of 2040 μmhos/cm for the Hagerstown discharged, 4 hours.

Phase II Results - Lithium

a. Mattapeake Silty Loam.

As shown in Figure 2.4-12, the lithium concentration of the discharged cell solution decreased from 496 mg/l initially, to 442 mg/l at 4 hours. From 4 hours to 168 hours the lithium concentration decreased at a consistent rate from 442 mg/l to 295 mg/l.

The live cell decant lithium concentration paralleled that of the discharged cell decant, decreasing initially from 713 mg/l to 605 mg/l at 4 hours. Final lithium concentration was 149 mg/l at 168 hours.

b. Lakeland Sandy Loam.

As shown in Figure 2.4-13, both decant solutions remained stable throughout the test period, after a decrease through the first four hours. The discharged cell decant consistently averaged 480 mg/l through 72 hours.

The live cell decant showed a lithium concentration of approximately 660 mg/l throughout the test period.

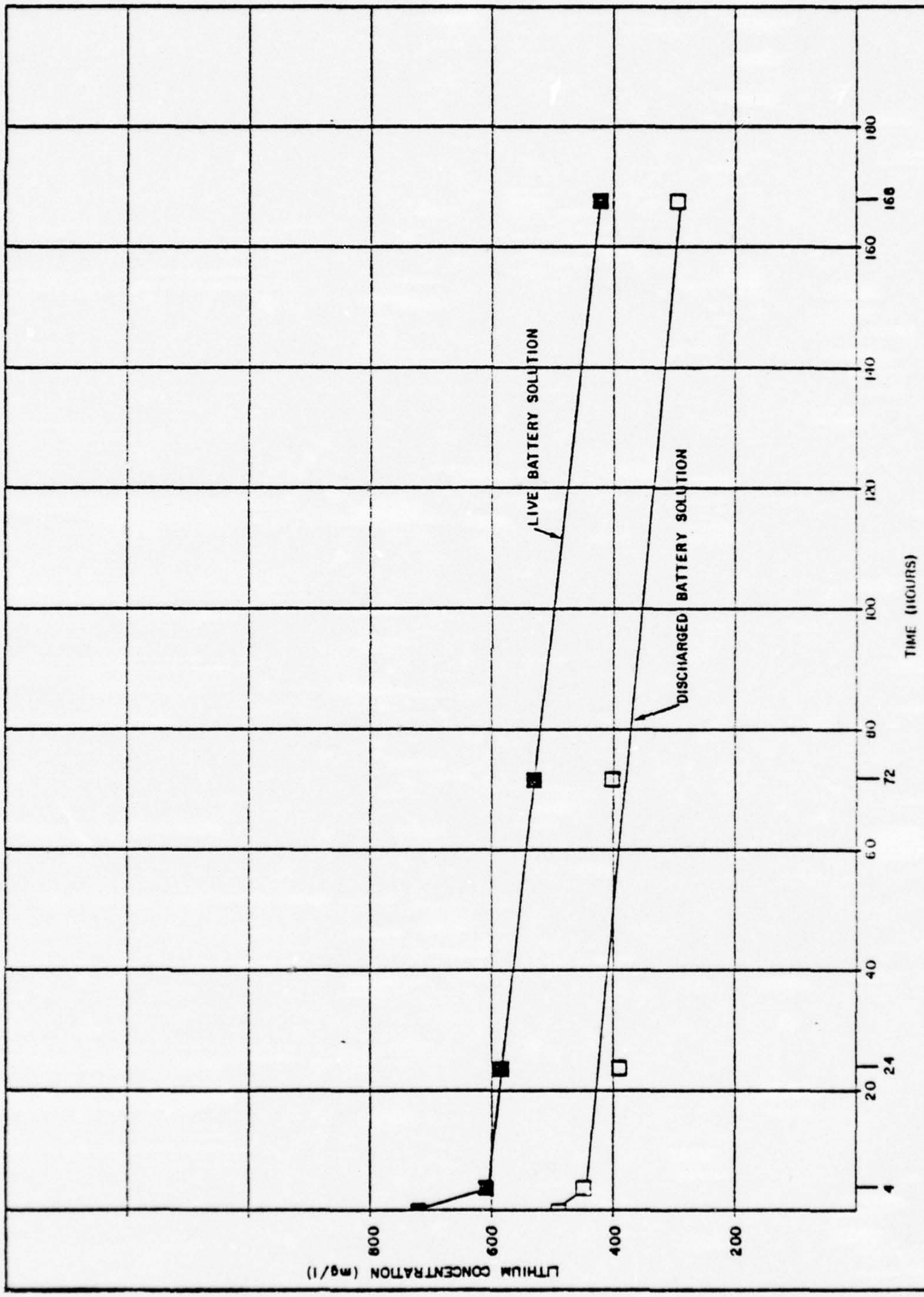
c. Hagerstown Silty Clay.

As shown in Figure 2.4-14, the lithium concentration of the discharged cell decant remained relatively constant throughout the test period at concentration of 460 mg/l at 168 hours, after an initial decrease, from 496 mg/l to 434 mg/l at four hours.

The lithium concentration of the live cell decant displayed a similar initial decrease from 213 mg/l initially to 580 mg/l at 4 hours. From 4 hours to 72 hours, lithium concentration remained stable and decreased to 440 mg/l at 168 hours.

d. Controls.

The highest lithium concentration of any of the controls was 0.023 mg.1 which was measured in the Mattapeake Control at 72 hours. This



■ LIVE BATTERY SOLUTION
□ DISCHARGED BATTERY SOLUTION

FIGURE 2.4-12

PHASE 2-MATTAPEAKE-LITHIUM vs. SHAKE TIME

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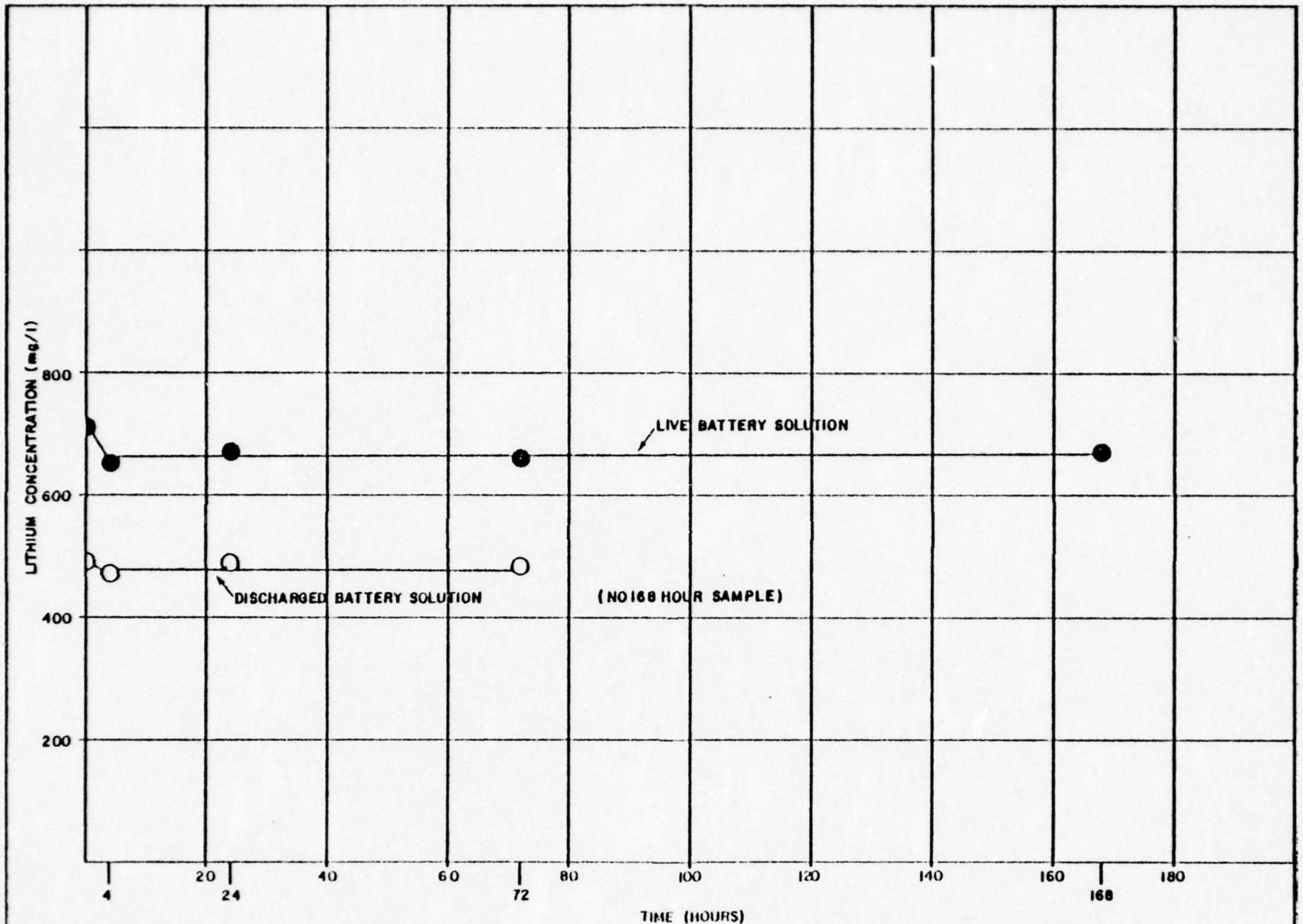

● LIVE BATTERY SOLUTION
○ DISCHARGED BATTERY SOLUTION

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FIGURE 2.4-13

PHASE 2-LAKELAND-LITHIUM vs. SHAKE TIME

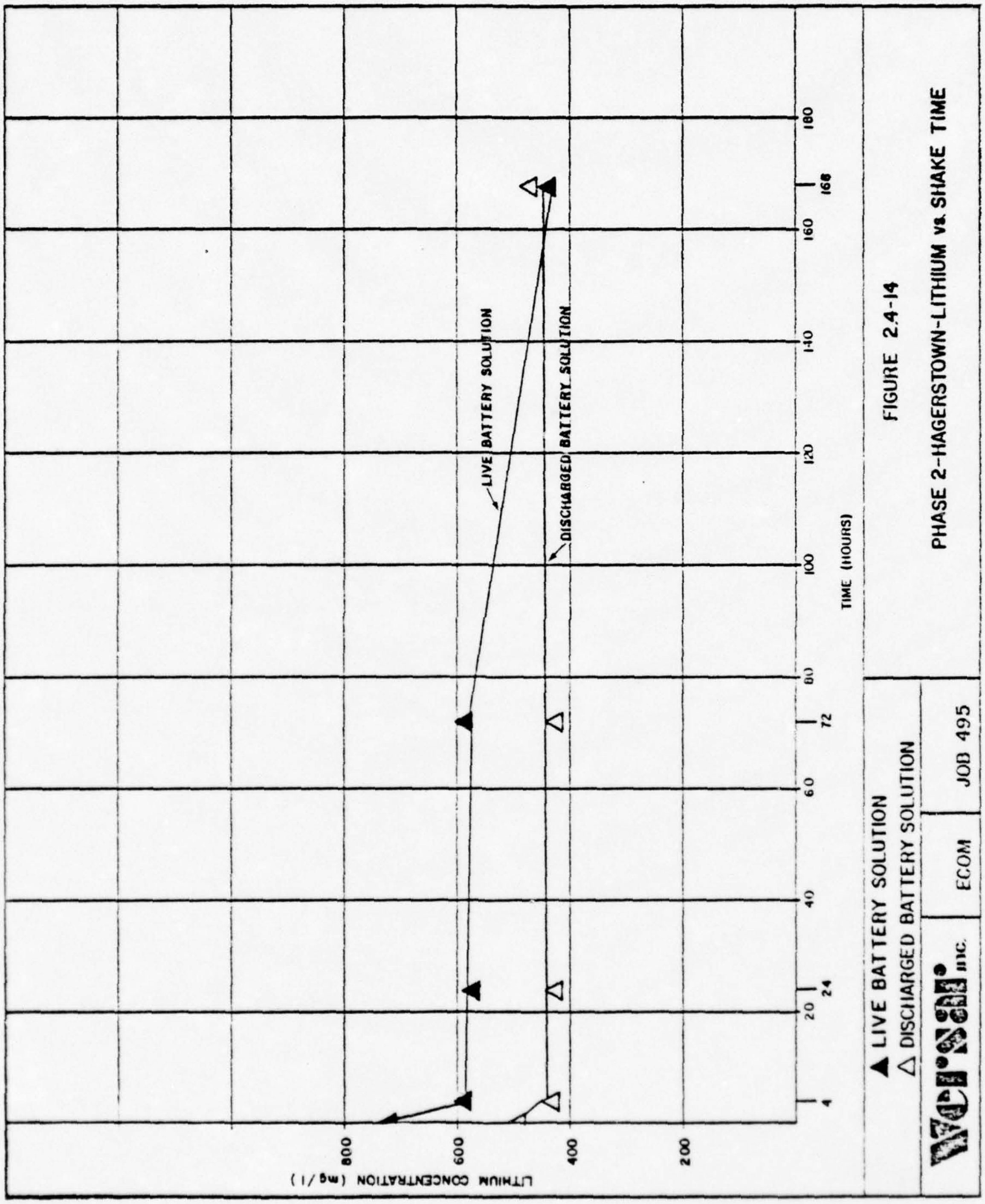


FIGURE 2.4-14

PHASE 2-HAGERSTOWN-LITHIUM vs. SHAKE TIME

value represents less than one percent of the lowest concentration of any test decants using the Mattapeake soil.

Phase II Results - Cyanide

a. Mattapeake Silty Loam.

As shown in Figure 2.4-15, the cyanide concentration of discharged cell decant was initially 1.3 mg/l, increased to 1.8 mg/l at 4 hours, decreased to 1.6 mg/l at 24 hours, essentially remained stable through 72 hours and dropped to 0.15 mg/l at 168 hours.

The live cell decant cyanide concentration remained below 0.10 mg/l throughout the test.

b. Lakeland Sandy Loam.

As shown in Figure 2.4-16, the discharged cell decant decreased in cyanide for the first 4 hours, from 1.3 mg/l to 0.19 mg/l, increased from 0.19 mg/l at 4 hours to 2.6 mg/l at 24 hours and decreased to 1.1 mg/l at 72 hours. No sample was obtained at 168 hours due to breakage of the flask during shaking.

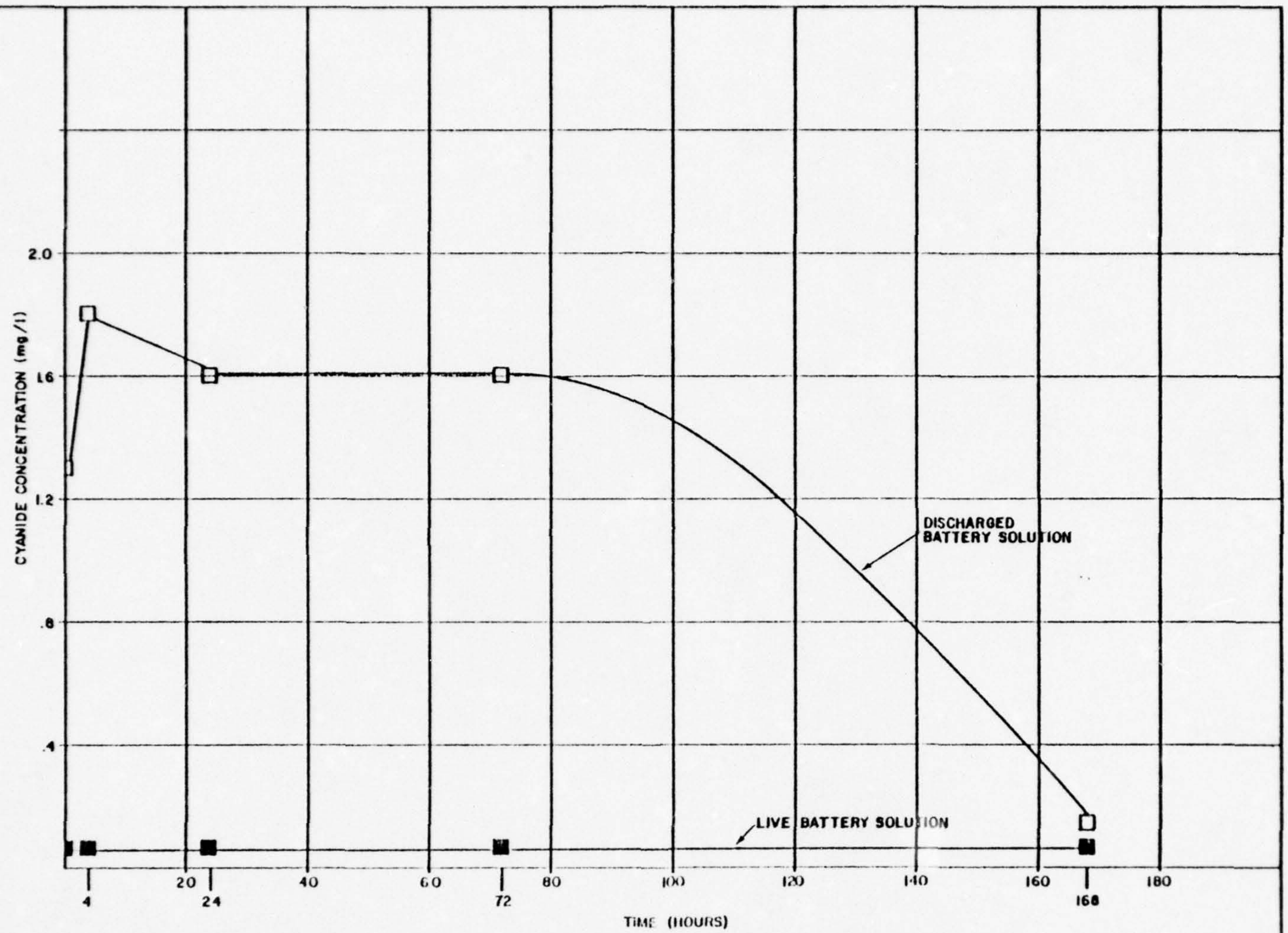
c. Hagerstown Silty Clay.

As shown in Figure 2.4-17, the cyanide concentration decreased in the discharged cell decant for the first four hours, from 1.3 mg/l to 0.20 mg/l, remained at that level until 24 hours, and increased to 0.98 at 72 hours. From 72 hours to 168 hours the cyanide concentration decreased from 0.98 to 0.15 mg/l.

The live cell decant increased to a high of 0.44 mg/l at 72 hours.

d. Controls.

With the exception of Lakeland control, cyanide concentration never exceeded 0.13 mg/l in control decanted samples. The Lakeland control reached a cyanide concentration of 0.53 mg/l at 72 hours, which was 2.7 times greater than the lowest concentration obtained from the Lakeland discharged decant of 0.19 mg/l.



■ LIVE BATTERY SOLUTION
□ DISCHARGED BATTERY SOLUTION

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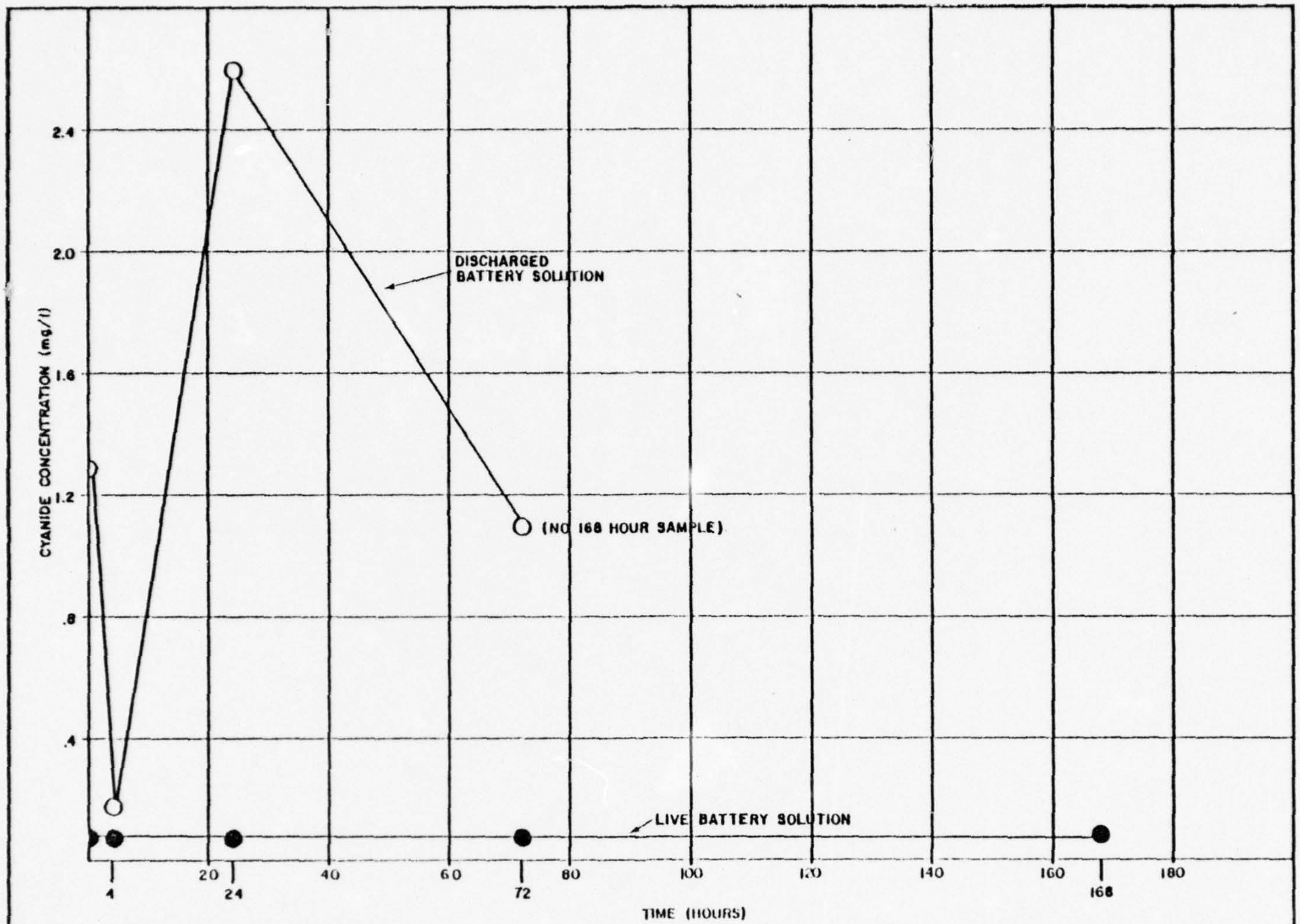
FIGURE 2.4-15

PHASE 2-MATTAPEAKE-CYANIDE vs. SHAKE TIME



● LIVE BATTERY SOLUTION ○ DISCHARGED BATTERY SOLUTION			FIGURE 2.4-16
Wersar inc.	ECOM	JOB 495	PHASE 2 - LAKELAND-CYANIDE vs. SHAKE TIME

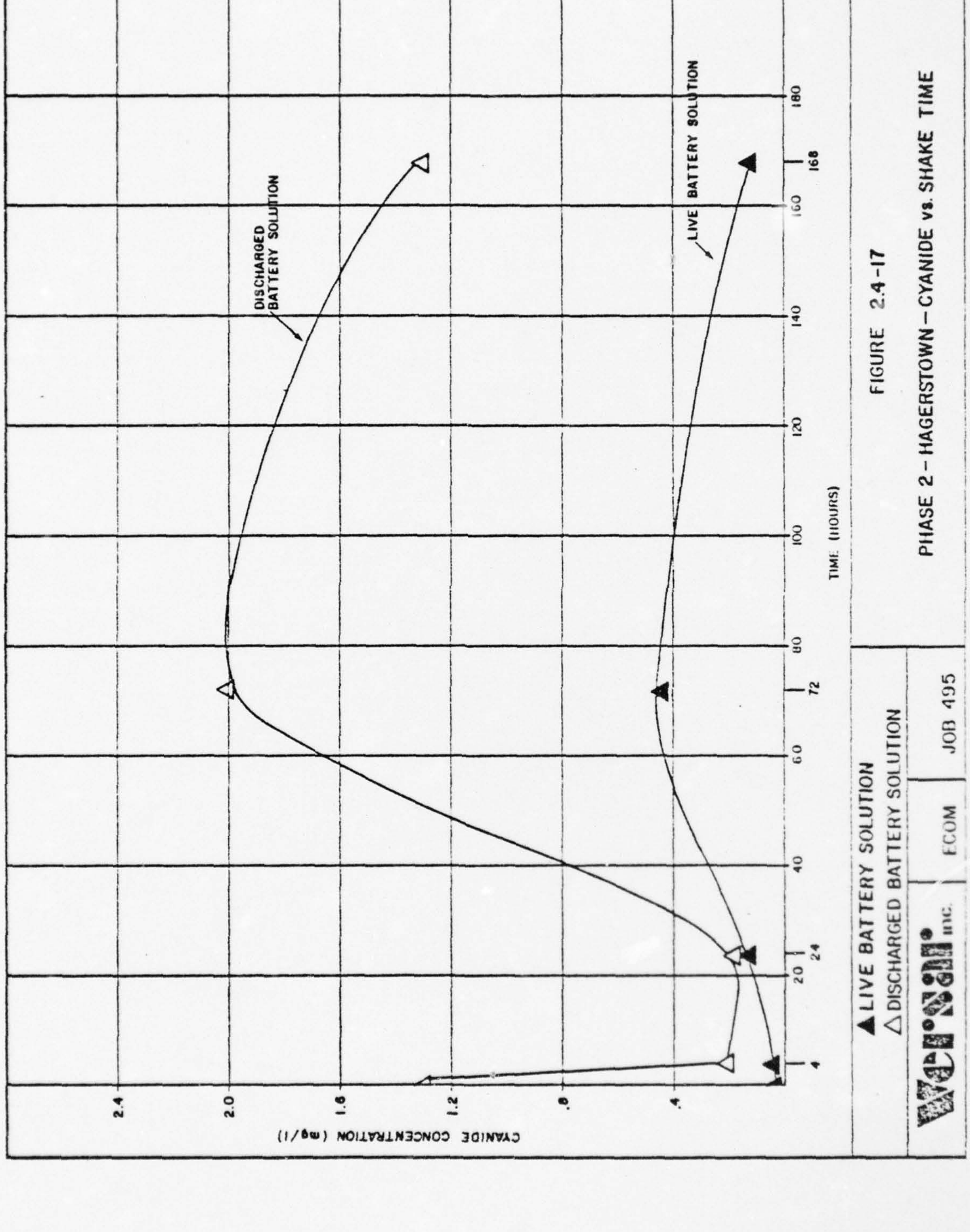


FIGURE 2.4-17

PHASE 2 - HAGERSTOWN - CYANIDE vs. SHAKE TIME

Summary of Phase II Tests

pH

Live Cell Slurries

There was an overall decrease in pH for both Lakeland and Mattapeake decants, and an increase for the Hagerstown decant.

Discharged Cell Slurries

Both Mattapeake and Lakeland decant changed less than one pH unit (pH 4-5). Overall the Hagerstown decant increased in pH by more than two pH units (pH 4-6.8) throughout the test.

Discharged Versus Live Cell Slurries

Mattapeake decant showed little variation between the live and discharged. The live cell decant decreased to pH 3.9; representing the lowest pH point in the overall test.

Both live and discharged Lakeland decant decreased in pH overall; the discharged cell decant pH was consistently 1.5 pH units below that of the live cell decant.

Both Hagerstown live and discharged cell decant followed a similar pH pattern with a variation of less than one pH unit.

Conductivity

Live Cell Slurries

All live cell decants displayed an increase in conductivity, although at varying rates, after an initial decrease. Mattapeake decant reached its highest conductivity (other than initial) after 72 hours, whereas Lakeland and Hagerstown required 168 hours to reach peak conductivity.

Discharged Cell Slurries

All discharged cell decanted solutions showed similar conductivity up to 72 hours, then displayed varying rates of increase.

Discharged Versus Live Cell Slurries

Both Mattapeake and Lakeland discharged cell decants paralleled the live cell decant conductivity trend, but at a consistently lower level.

The Hagerstown discharged cell decant conductivity consistently varied less than 500 μmhos/cm from that of live cell decant.

Lithium

The lithium concentrations for Hagerstown and Lakeland decanted samples remained essentially constant throughout the test period after initial decrease until four hours. The lithium concentrations of both Mattapeake live and discharged samples, decreased at a constant rate throughout the test period.

In all cases, the lithium concentrations of discharged cell samples were less than the concentrations of live cell samples. The lithium concentration of the controls reached a maximum of 0.20 mg/l with the Lakeland control.

Cyanide

Cyanide concentration in discharged cell decants reached maxima of 2.0 mg/l for Hagerstown soil, 2.6 mg/l for Lakeland soil, and 1.3 mg/l for Mattapeake soil.

Trends of both lithium and cyanide displayed on Figures 2.4-12, 13, 14, 15, 16 and 17, should not be directly attributed to soil adsorption. Even though test solutions were allowed to stablize for two weeks, equilibria with the soils cannot be assumed and therefore the results presented can only be interpreted as trends observed in these test situations. To formulate cause and effect relationships, a much more detailed and controlled study would have to be performed.

Additional information regarding soil adsorption may be obtained if the Hagerstown and Mattapeake column tests are continued. Analysis of the leachate and possibly the soil itself would allow evaluation of the removal of cyanide from the leachate passing through the column. This data would be compared to the conditions documented in the Lakeland sandy soil.

3. Phase III Tests

Methods and Materials

The following materials were required in this Phase.

- 9-4" x 4 1/2" OD x 3/16" W.T. Glass Columns*
- 9 - Wire mesh retainers
- Column Rack
- 12 Cells - six discharge, six live
- 9 - 500 ml Erlenmeyer flasks
- Liquid Nitrogen
- Nitrogen Gas
- Distilled H_2O
- $1m^3$ Lakeland Sandy Loam
- $1m^3$ Hagerstown Silty Clay Loam
- $1m^3$ Mattapeake Silty Loam
- $1/2m^3$ Coarse Gravel ($\sim$ 1/4" Diameter)
- $1/2m^3$ Fine Gravel (1/8" Diameter)
- Assorted Tygon Tubing, Rubber Stoppers, and Hose Clamps.

*Equipped with outlet and overflow nipples.

The methods used are as follows:

a. In all columns, two inches of coarse gravel, two inches of fine gravel and a mesh retainer were added previous to packing of test soils.

b. For each of the three soil types, three columns were packed to a level of 36 inches.

c. All columns were fitted with overflow hoses, N_2 supply, flow regulating clamps and collection flasks.

d. An H_2O head of $\sim$ 3 inches was maintained during a one week period at a flow from the column of 5-10 ml/hr, thus insuring soil saturation.

e. Six cells, previously discharged, and six live cells were placed in liquid nitrogen for 30 minutes prior to cutting.

f. Cells were cut lengthwise on a mechanical hack saw, actual cutting took from 15-25 seconds per cell. Time from cutting to placement in the columns took from 15 to 30 seconds.

g. For each soil type, 2 cut discharged cells (four halves) were placed in one column; two cut live cells were placed in the second column; the third column in each set was maintained for a soil control.

h. All cell halves were placed two inches below the soil surface. To prevent uncovering during H_2O head replenishment, each column was capped with two inches of coarse gravel.

i. No flow restriction was applied to any Hagerstown or Mattapeake column. Flow in Lakeland soil was restricted to a maximum of 400 ml/day.

j. Leachate samples were taken when a collected volume of 200 milliliters or more was obtained.

k. Conductivity, pH and temperature were checked and recorded for every 200 ml sample obtained. The 200 ml sample was divided into two 100 ml portions; one 100 ml sample was preserved for lithium and sulfite analyses; the second 100 ml sample was adjusted with 10% NaOH to a pH of 12 and held for cyanide analysis.

Note: Upon placement of opened cells in columns, flaming occurred, persisting for 2-3 minutes.

Lakeland Results

pH

The determined pH of each leachate portion from Lakeland columns are plotted against maximum cumulative volume (Lakeland live - 7,035 ml) in Figure 2.4-18. Denotations of both (cumulative) volume and number of days in text are relative to actual battery fragment implantation into soil columns.

The first leachate sample from discharged cell column was collected on the second day from startup (accumulative volume of 300 ml) and had a pH of 6.8. From the fourth day (1270 ml) to the 13th day the pH averaged 6.4 with little variation (±.06 pH units).

This stabilization was followed by an increase in pH to the 24th day (4635 ml) to 7.6, followed by a decreasing trend for the duration of the 41 day test period to pH 7.0 (6395 ml).

Leachate portions from Lakeland live column increased more in pH than did Lakeland spent portions.

The portion obtained on the second day (600 ml) had a measured pH of 5.6. pH increased to 11.8 on the seventh day (2805 ml) and steadily decreased through the 41st day (7035 ml).

Control samples indicated little pH variance of Lakeland Sandy Loam having an average pH of 6.7 ± .5.

Conductivity

The conductivity of all leachate portions are plotted against accumulative volume of Figure 2.4-19. Within 5 days from startup, conductivity of spent cell column had peaked at 12,050 μmhos/cm (1520 ml) followed by a decrease to 5,500 μmhos/cm at 15 days (3075 ml). At 19 days (3575 ml) conductivity was 10,600 μmhos/cm and decreased to 266 μmhos/cm at 41 days (6395 ml).

Live cell leachate conductivity increased from an initial 130 µmhos/cm after two days (600 ml) to 22,000 µmhos/cm at seven days (7805 ml) and receded to 1,020 at 41 days (7035 ml).

Control conductivity values were consistently below 250 umhos/cm.

Sulfite

Sulfite concentrations of each portion from Lakeland discharged cell column plotted against cumulative volume (Figure 2.4-20) shows an abrupt increase from an initial concentration of 0.18 mg/l at two days (300 ml) to 11,100 mg/l at 7 days (1820 ml). From the seventh (1820 ml) to the 17th day (3275 ml) sulfite concentration was consistently above 10,000 mg/l and decreased to 0.9 mg/l at 41 days.

Sulfite concentrations of Lakeland live cell leachate rose to a high of 11,400 mg/l at 6 days (2305 ml), and decreased at a steady rate to 6.9 mg/l at 41 days (7035 ml).

Sulfite concentrations of control portions averaged 0.7 mg/l with a maximum of 5.0 mg/l at 18 days (3835 ml).

Lithium

Lithium concentration of discharged cell leachate increased through ten days (2200 ml) to a maximum of 1,999 mg/l, and decreased gradually to 17.2 mg/l on the 41st day (6395 ml).

Live cell leachate lithium concentration increased to a maximum of 3,065 mg/l after seven days (2805 ml). From the seventh day to the 41st day the lithium concentration decreased to 66.7 mg/l at 41 days (7035 ml).

Control leachate had a maximum lithium concentration of 3.45 mg/l on the 16th day although the average lithium concentration was 0.9 mg/l. It is because the control lithium concentration was relatively low that values were not subtracted from test column lithium values. (i.e. naturally accurring lithium ions in the soil do not contribute significantly to overall lithium concentration of test columns).

Cyanide

Cyanide concentration of leachate from discharged cell reached a maximum of 39.0 mg/l after ten days (2220 mls), and decreased consistently to 0.59 mg/l at 28 days (5680 ml).

Live cell leachate cyanide concentration reached a maximum of 1.40 mg/l after six days (2305 ml), and decreased to less than 0.025 mg/l at 41 days (7035 ml).

Note when making visual comparisons between live and spent cell leachate as plotted on Figures 2.4-20 and 2.4-21, that cyanide concentration scales are not the same.

The maximum value of cyanide obtained from control column leachate was 2.14 mg/l on the eleventh day (2275 mls); the overall average value was 0.044 mg/l cyanide. (Again, cyanide concentrations of control leachate were not subtracted from test results.)

Mattapeake and Hagerstown Results

At the time of this report the following volumes had been leached from Mattapeake and Hagerstown columns.

Hagerstown			Mattapeake		
Live	Discharged	Control	Live	Discharged	Control
1435 ml	1250 ml	5650 ml	575 ml	885 ml	2420 ml

Since actual battery component break through occurred after 2020 mls and 2305 mls of leachate from Lakeland spent and live cell columns, no comparisons between soil type characteristics could be made at this time. Nor can comparisons be made until equivalent volumes of leachate are obtained from Mattapeake and Lakeland columns. (Although chemical migration through soil is not limited by water flow through that soil, but rather a function of chemical species involved).[7] A situation worth noting is that the presence of lithium cells and/or cell components in Mattapeake or Hagerstown soil types inhibits flow through those soil types, evident when comparing cell column flow with control column flow.

Versar recommends continuing the column tests to identify the chemical characteristics of the leachate passing through the Hagerstown and Mattapeake soils. As an ultimate step, soils could be excavated from the columns containing the cells and analysed for their cyanide concentrations. This step would be necessary to quantify the amount of cyanide uptake if breakthrough of the cell components in the leachate did not occur.

SUMMARY

pH

The pH values for spent cell column leachate were consistently in the range of 6.2 to 7.5 compared to pH values of live cell column leachate which remained alkaline (10-12) after seven days (2805 ml).

Conductivity

Conductivity of the spent cell leachate peaked twice; the first peak was 12,050 µmhos/cm at seven days (1820 ml) - the second peak was 10,600 µmhos/cm at 19 days (3575).

The conductivity of live cell leachate reached a maximum of 22,000 µmhos/cm after seven days (2805 ml).

It is reasonable to conclude that the observed conductivity increases in both live and spent cell leachate are due to the presence of cell constituents in the soil columns.

Sulfite

The maximum sulfite concentration of the spent cell leachate (39 mg/l) was 27 times greater than the maximum obtained from live cell leachate (1.4 mg/l). Upon comparison with control column leachate sulfite concentration, it is apparent that lithium cell constituents release sulfites to surrounding environments and that Lakeland Sandy Loam does not effectively contain sulfite. (This is not to say that sulfite is or is not absorbed by Lakeland Sandy Loam).

Lithium

Lithium concentration of discharged cell column leachate reached a maximum value of 1,999 mg/l at ten days (2200 ml) compared to a maximum of 3,035 mg/l after seven days (2,805 ml) for live cell column leachate.

Cyanide

Lithium concentration of discharged cell column leachate reached a maximum of 39 mg/l after ten days (2220 ml) which is 28 times greater

than the maximum of 1.4 mg/l at six days (2305 ml) for live cell column leachate.

The amount of cyanide which passed through the discharged cell column was 52.33 mg.

4. Conclusions

The laboratory tests illustrate specific chemical and physical effects which could result in serious environmental consequences, and as such, may limit the battery disposal options.

As discussed above, Versar recommends that additional cell testing be done and that column leachate testing be continued. Additional cells need to be analyzed to provide an adequate data base for statistical review. The column testing needs to be continued to assess the sorption of cyanide by silt and clay type soils.

Chemical Effects

The most significant result of the laboratory testing was the detection of cyanide present in solutions of distilled water exposed to one or two cells. Solutions from discharged cells contained cyanide in concentrations ranging from 11 mg/l to 43 mg/l, higher than the range for live cell solutions, which were less than 1.5 mg/l. Cyanide concentrations in solutions which were allowed to stand for two weeks were lower (< 3.9 mg/l), possibly because of volatilization of hydrogen cyanide (HCN).

Lithium concentrations in Phase I ranged from 280 mg/l to 1,070 mg/l. The upper value represents a concentration that would result from complete dissolution of the lithium in the cell. In Phase III, lithium concentrations were higher in the live battery leachate than in the dead battery leachate reflecting the change of lithium in the cell during discharge to a less soluble form.

The solutions showed no uniform trend in pH. In Phase I, two of the discharged cell and one of the live cell solutions had an initially high pH (between 11 and 12), which decreased to between 8.8 and 10.6. The other live cell had an initial pH of 6.4 and gradually increased to pH 10.5. Phase III data contrasted with Phase I data as the pH for the live cell solution was much higher (between 10 and 12) than the pH of the discharged cell between 6.0 and 7.5).

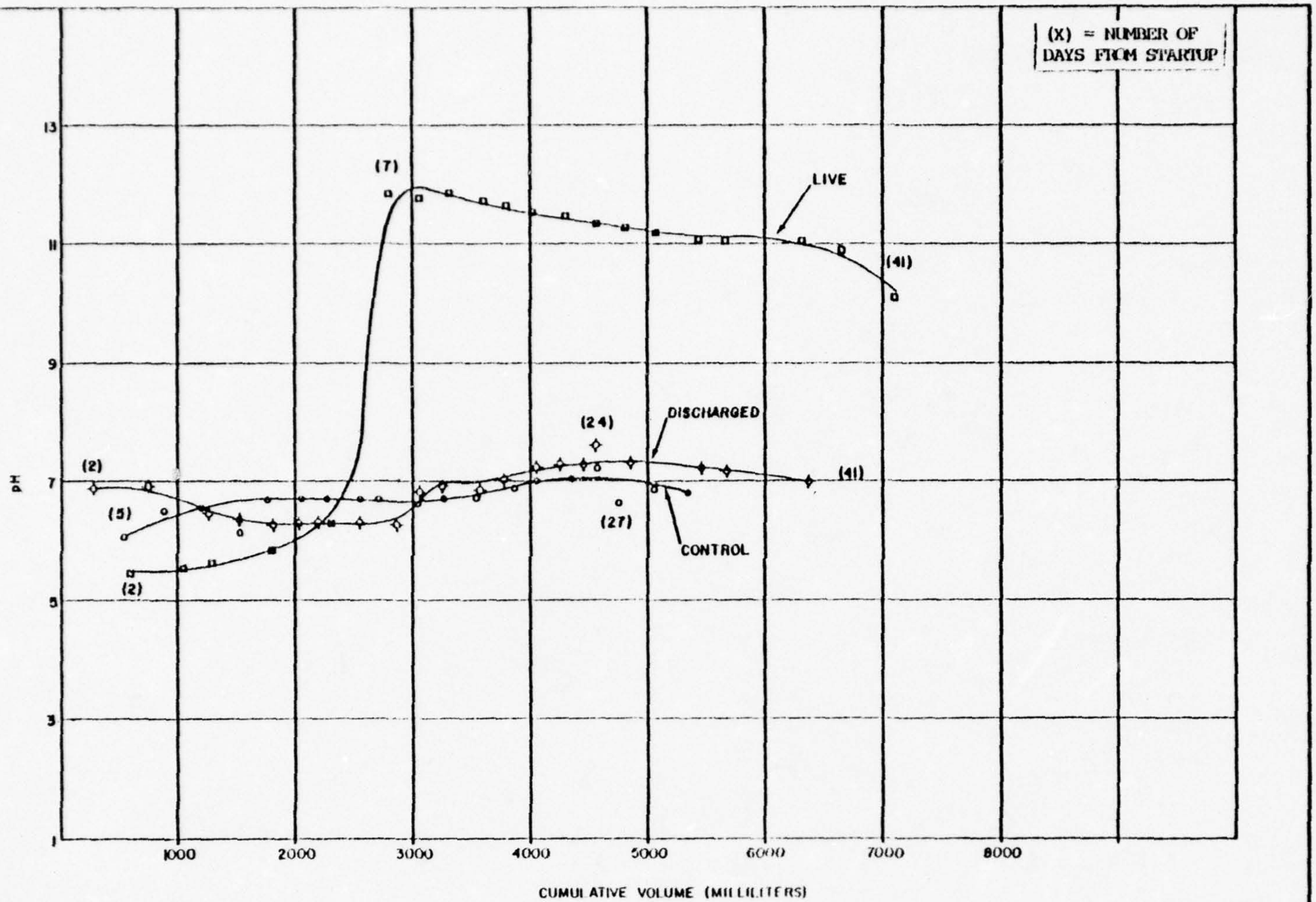
During cutting of the cell, a strong irritating, pungent odor emanated from the battery. This odor was believed to be sulfur dioxide (SO_2). Although no measurements were taken, the fumes were highly irritating.

Physical Effects

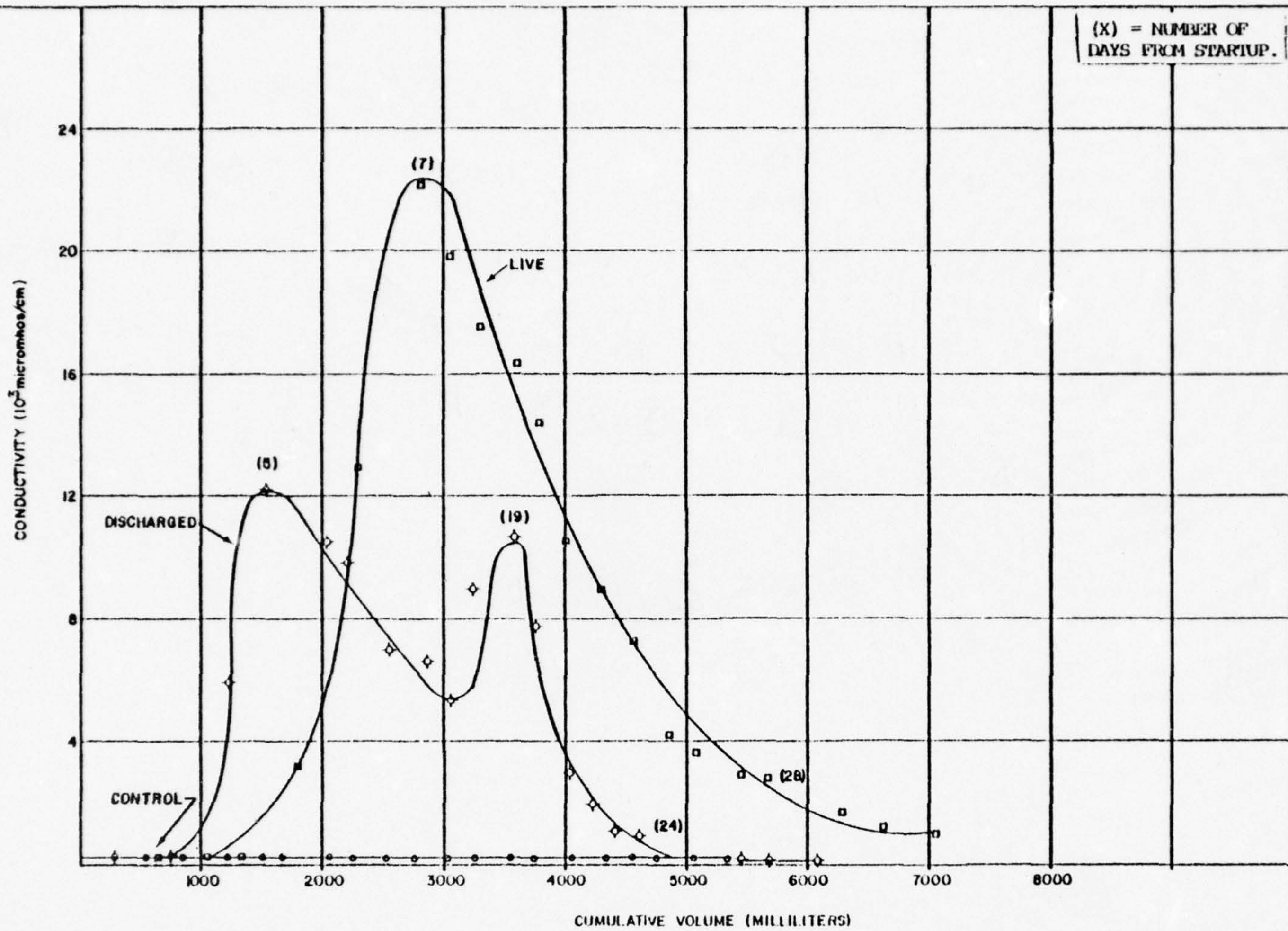
One of the most important physical effects observed was the violent flaming of the opened cells when contacted by water or soil. Several of the glass columns used in Phase III were pocked by the heat released by reaction of the open cells and water. This violent reaction could cause problems during cell disposal.

Another physical effect pertinent to disposal is the decrease in permeability caused by percolation of the cell solutions through the 'tight' soils (Mattapeake silty loam, Hagerstown silty clay loam) used in Phase III. The flow of leachate through columns of both live and discharged cells in both of the these soils was reduced to about 30 percent of that in the control columns of similar soils. In these soils and under field conditions chemical diffusion of contaminants may be more important than physical dispersion of the contaminants in controlling the distribution and mobility of soluble materials.[7]

In the experimental columns of Lakeland sandy loam in Phase III, there was a noticeable change in color of the leachate as compared to the leachate in the control column. The leachate from the control was light brown and appeared to be of normal viscosity, whereas the leachate from both the live and discharged cell solutions was dark brown to black and appeared more viscous than water from the control solution.



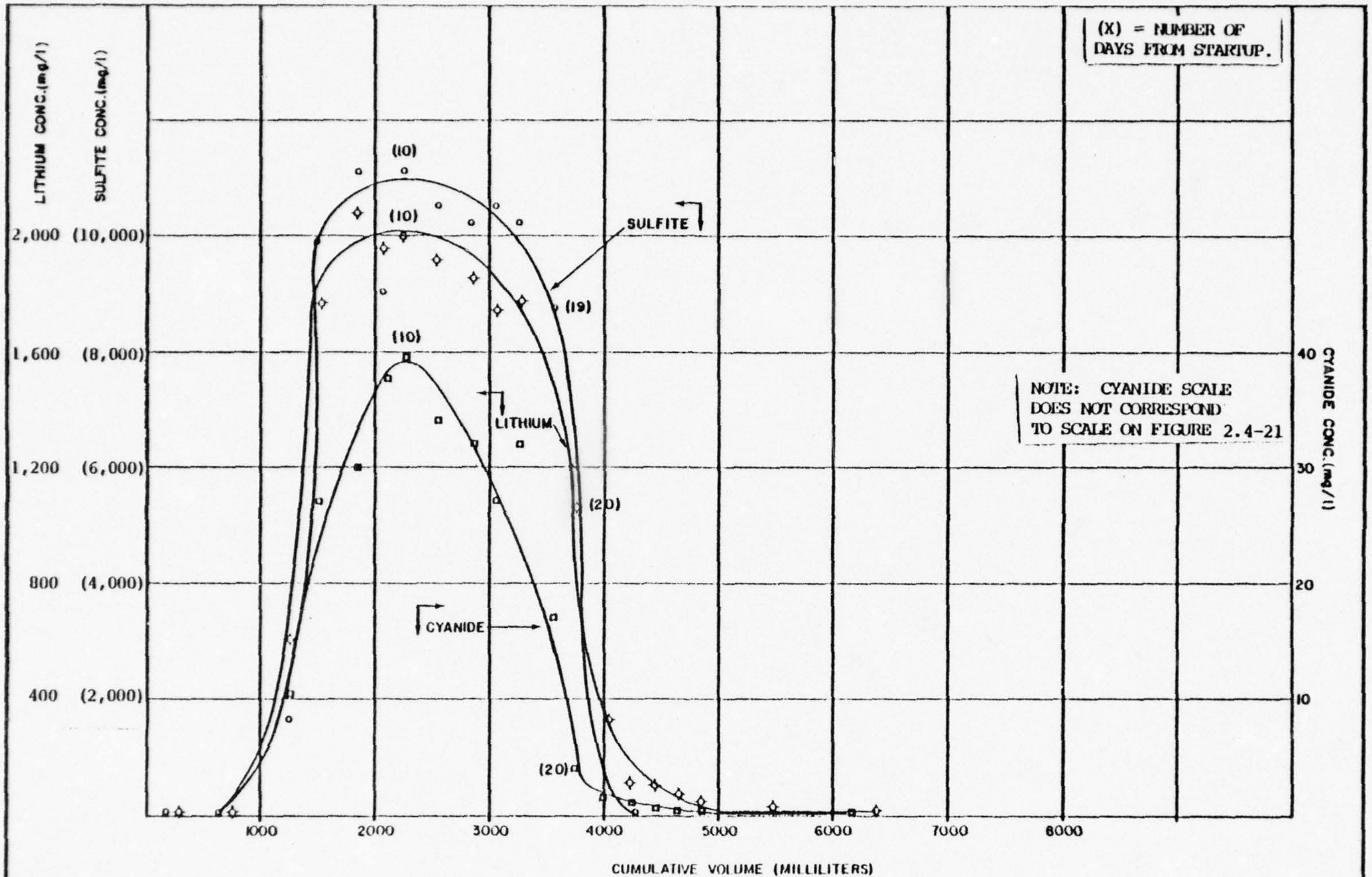
▫ LIVE ◦ CONTROL	✧ DISCHARGED		FIGURE 2.4-18 PHASE 3 pH vs. CUMULATIVE VOLUME OF LAKELAND DISCHARGE
Versar inc.	ECOM	JOB 495	



□ LIVE ◇ DISCHARGED
○ CONTROL

Versar inc. | ECOM | JOB 495

FIGURE 2.4-19
PHASE 3
CONDUCTIVITY vs. CUMULATIVE VOLUME
OF LAKELAND DISCHARGE



▫ CYANIDE
◦ SULFITE
✧ LITHIUM

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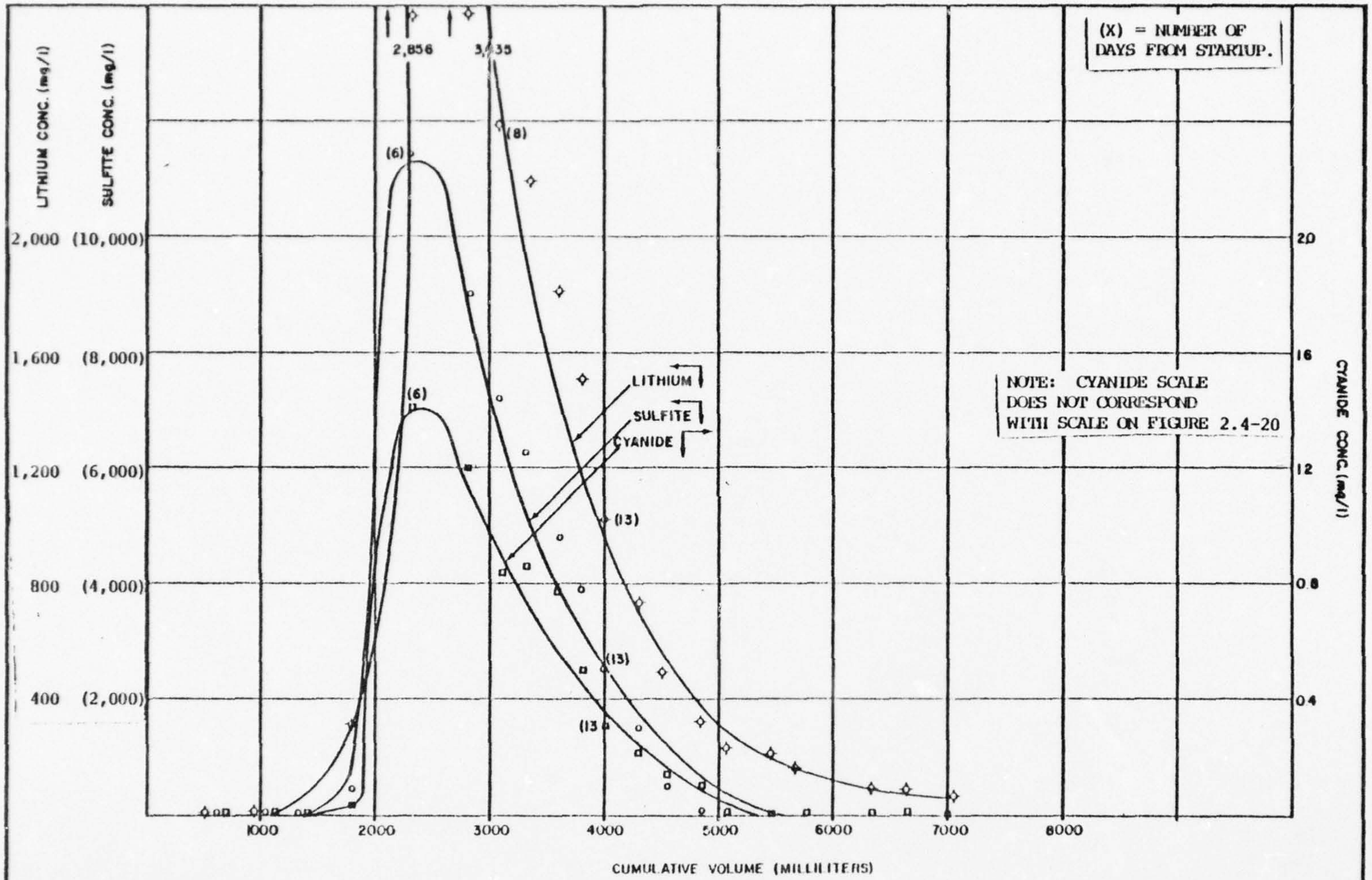
FIGURE 2.4-20
PHASE 3
LAKELAND DISCHARGED LITHIUM, CYANIDE & SULFITE CONCENTRATIONS vs. CUMULATIVE VOLUME



□ CYANIDE
○ SULFITE
◇ LITHIUM

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FIGURE 2.4-21
PHASE 3
LAKELAND LIVE LITHIUM, CYANIDE & SULFITE
CONCENTRATION vs. CUMULATIVE VOLUME

III. RECOMMENDATIONS FOR DISPOSAL

A. Summary of Conclusions

Lithium - acetonitrile - SO_2 cells can release high levels of cyanide when the components of the cell are exposed to the environment. Phase 1 lab results show that an average discharged cell releases approximately 160 mg of cyanide. The average fatal dose for humans is between 50 and 60 mg.[4] The cyanide apparently results from a chemical reaction between lithium and acetonitrile in the discharged cell in the absence of SO_2. A control with acetonitrile in the same concentration as that in the test showed a one percent cyanide dissociation. Lab results indicate that live cells (non-discharged) release much smaller quantities of cyanide.

In addition to cyanide, which is the most toxic of disposed cell constituents, sulfur dioxide and lithium also exert toxic effects on plants and animals.

The cells also have hazardous properties in that they may flame whe[n] opened. Because of the possibility of igniting other materials in disposal sites and the potential for release of dangerous quantities of gaseous hydrogen cyanide, the cells require isolation from other wastes.

The reduction in permeability of Lakeland sandy loam (Phase 3) indicates that disposal of the cells may affect leachate percolation, causing a reduction in flow of ground-water beneath landfill disposal sites. This could result in sorption of cyanide by silt and clay type soils along with not only increased concentration, but also more long term confinement of the leachat[e]

B. Disposal Recommendations

Based upon the data available at the present time for the toxic and hazardous properties of the cell, small quantities of cells should be disposed of in the same manner as large quantities of cells. It is our opinion at this time that the best options suitable for disposal of lithium cells are: (1) secured landfills; and (2) disposal ponds with provisions for leachate control and monitoring, documentation and runoff control.

Additional work regarding further cell characterization and soil sorption data for cyanide is necessary before a final recommendation can be made regarding disposal of lithium cells in sanitary or special purpose lan[d]

Secured landfills are acceptable because these landfills provide for proper geological placement of wastes as well as monitoring wells and leachate control. Also, the location of other wastes are known, and the secured landfill operator is equipped to handle potentially flammable materials.

Disposal ponds are acceptable if they can provide protection equivalent to that afforded by secured landfills. This would include some means of preventing contamination of ground and surface water, such as liners and runoff control. Leachate monitoring and control would also be necessary, as liners often leak.

Special purpose and sanitary landfills, based on the data available, appear unacceptable at this time because they do not provide leachate monitoring and control. However, the results of additional cell testing and soil column leachate tests may modify the acceptability for these disposal options.

Incineration is impractical due to volatilization of hydrogen cyanide, sulfur dioxide and lithium and limitations as to heavy metal concentrations. Also important is the danger of explosion.

Ocean dumping and deep well injection are unacceptable because these methods do not control release of cyanide. In addition, permits for these activities are very difficult to acquire.

Municipal sewers are unacceptable for disposal of the soluble components of lithium cells because most sewage treatment plants do not accept wastes which could adversely affect biological treatment organisms.

Recovery and reuse has not been shown to be technologically or economically feasible.

IV. REFERENCES

References used in compiling toxicity data are cited by footnotes in Appendix B, and follow the toxicity profile of each substance. Other references used in this study are presented, by author, in alphabetical order below.

1. American Public Health Association. 1975. Standard Methods for the Examination of Water and Wastewater. APHA, AWWA. Washington, D.C.

2. Brunner, D.R., and D. J. Keller. 1972. Sanitary Landfill Design and Operation. U.S. EPA, SW-65ts. Washington, D.C.

3. Environment Reporter - State Regulations. 1976. Bureau of National Affairs. Washington, D.C.

4. EPA, Oil and Hazardous Materials Technical Assistance Data Systems (OHMTADS). 1977. Printout on Acetonitrile. Washington, D.C.

5. Fenn, D.G., K.J. Hanley, and T.V. DeGeare. 1975. Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites. E.P.A./530/SW-168. Washington, D.C.

6. Frost, R.R., and R.A. Griffin. 1976. Effect of pH on adsorption of arsenic and seleniun from landfill leachate by clay minerals. Soil Sci.Soc. of Am.J.

7. Gregg, D.O. and K.G. Kennedy. 1975. Movements of chemical contaminants in ground water. In Environmental Aspects of Chemical Use in Well-Drilling Operations. Houston, Texas.

8. Griffin, R.A., R.R. Frost, N.F. Shinp. 1976. Effect of pH on removal of heavy metals from leachates by clay minerals. Presented at the "Hazardous Waste Research Symposium: Residual Management Land Disposal". Tuscon, Arizona.

9. Maryland, State of. 1976. An Act Concerning Natural Resources - Safe Disposal of Hazardous Substances No. 977. Annapolis, Md.

10. Minnesota, State of. 1974. Hazardous Waste Disposal Act Amendments. St. Paul, Minnesota.

11. Oklahoma, State of. 1975. Oklahoma Controlled Industrial Waste Disposal Act. Bill No. 1811. Oklahoma City, Okla.

12. Oregon Dep't of Env. Quality. 1973. Hazardous Waste Management Planning. Portland, Ore.

13. Texas Water Quality Board. 1975. Industrial Solid Waste Management Regulation Order No. 75-1125-1. Austin, Tx.

14. U.S. Gov't. 1976. Resource Conservation and Recovery Act of 1976. PL 94-580. Washington, D.C.

15. Versar, Inc. 1975. Assessment of Industrial Hazardous Waste Practices, Storage and Primary Battery Industries. 449 EPA/530/SW-102c. Washington, D.C.

16. Washington, State of. 1976. Hazardous Waste Disposal Act. Bill No. 2038 Olympia, Washington.

APPENDIX A

Toxicity of Selected Battery Components and Their Breakdown Products

The toxicity of acetonitrile; hydrogen cyanide; lithium and its compounds; propylene carbonate; and sulfur dioxide and sulfurous acid are discussed in the following pages. Appendix A concludes with a glossary of toxicity terms and symbols.

Acetonitrile

Acetonitrile: CH_3CN (ethanenitrile, methyl cyanide). Clear, colorless liquid at standard temperature and pressure (STP). Aromatic odor.

Natural Occurrence, Characteristics, Associated Compounds

The only known natural occurrence of acetonitrile is in coal tar, and only in small amounts.

In water, the dissociation of acetonitrile into methyl and cyanide ions is not appreciable. Aqueous acetonitrile is slowly degraded by biological and chemical action to release cyanides. Potentially persistent cyanides resulting from bio- and chemo-degradation is the main environmental problem associated with acetonitrile.[2]

Although relatively non-toxic, acetonitrile is extremely flammable, and releases toxic combustion products. It is possible that acetonitrile in the lithium battery could be ignited by the energy given off by the reaction between metallic Li and H_2O.

A related compound, the insecticide methomyl, is rapidly and almost completely degraded into carbon dioxide and acetonitrile by plants (corn, tobacco and cabbage) and rats. Methomyl fed to dogs and rats had no effect in doses up to 100 ppm.[3]

Physico-Chemical Properties: Molecular wt. 41.05: melting point -45.7°C: boiling point 81.6°C: density 786@20°C: vap.press. 100 mm Hg@27°C: soluble in all proportions in H_2O. Flash point: 12.8°C: lower flammability limit: 4.4%: upper flammability limit: 16%: lower explosive limit: 3.05%: upper explosive limit: 17%.

Toxic Properties, Health Effects

Acetonitrile exerts toxic effects only when administered in very high dosages. Toxicity data are given below.

a. Mammals

Animal	Route	Parameter	Dosage
Rat	Oral	LD_{50}	3,800 mg/kg[2]
Rat (young)	Oral	LD_{50}	200 mg/kg[2]
Rat	Oral	LD_{50}	2,460 mg/kg[4]
Guinea pig	Oral	LD_{50}	180-450 mg/kg[5]
Rat	Inhalation	LCL_0-4 hrs.	8,000 ppm[2]
Rat	Inhalation	LD_{10}	4,000 ppm[4]
Rat	Inhalation	LD_{33}	8,000 ppm[4]
Rat	Inhalation	LD_{57}	32,000 ppm[4]
Rabbit	Skin	LD_{50}-14 days	4,000 mg/kg[2]
Rabbit	Skin	LD_{50}	5,000 mg/kg[6]
Rabbit	Sub-cutaneous	MLD	130 mg/kg[1]
Mouse	Sub-cutaneous	MLD	600 mg/kg[6]
Mouse	Sub-cutaneous	MLD	700 mg/kg[6]
Rat	Sub-cutaneous	LD	500-3900 mg/kg[6]
Rabbit	Sub-cutaneous	MLD	105 mg/kg[6]
Rabbit	Sub-cutaneous	MLD	130 mg/kg[6]
Monkey	Sub-cutaneous	LD	720-800 mg/kg[6]
Mouse	Sub-cutaneous	LDL_0	700 mg/kg[7]
Rabbit	Sub-cutaneous	LD_{50}	1.25 ml/kg[4]
Rabbit	Sub-cutaneous	LD_{50}	0.50 ml/kg (75% CH_3CN in H_2O)[4]
Mouse	Interperitoneal	LD_{50}	1,920 mg/kg[7]

Cases of human death after long exposure to high concentrations of acetonitrile have been reported. Hann and Jensen reported that the human toxicity of acetonitrile is slight with LD_{50} between 500 and 5,000 mg/kg.[8]

b) Fish

Animal	Parameter	Conc. (mg/l)	Exposure (hrs.)	Hardness
Fathead minnow	TLm	1,150	24	Hard[2]
Fathead minnow	TLm	1,050	48	Hard[2]
Fathead minnow	TLm	1,000	96	Hard[2]
Fathead minnow	TLm	1,050	24	Soft[2]
Fathead minnow	TLm	1,000	48	Soft[2]
Fathead minnow	TLm	1,000	96	Soft[2]

b. Fish (continued)

Animal	Parameter	Conc. mg/l)	Exposure (hrs.)	Hardness
Sunfish	TLm	1,850	24,48, and 96	Soft[2]
Guppy	TLm	1,650	24,48, and 96	Soft[2]
Bullhead minnow	TLm	1,000	4 days	Hard or Soft[9]
Bluegill Sunfish	TLm	1,850	4 days	Soft[9]

Using the criteria listed in the 'Registry of Toxic Effects of Chemical Substances,[7] acetonitrile is an insignificant hazard to aquatic life.

c. Birds

Animal	Route	Parameter	Dosage
Pigeon	Im	LD	4,000 mg/kg[6]

d. Amphibians

Animal	Route	Parameter	Dosage
Frog	scu	MLD	9,100 mg/kg[6]

Acetonitrile exhibits toxic properties when introduced by eye contact, inhalation, ingestion, or skin penetration or irritation. Physiological effects of acetonitrile toxification are apparently due to catabolism into cyanide and hydrocyanic acid and include the following:

Rats:[10]
- Purkinje cells show pyknosis and cytoplasmic hyperchromatophilia.
- Degenerative changes in the testes and kidneys.
- Chronic infectious alterations.
- Concentration of HCN in heart, brain, kidney, spleen, skin.
- Severe dyspnea.
- Cyanosis.
- Accumulation of acetonitrile in kidney, liver, intestine, muscle, testis, heart, and stomach.
- Anuria.
- Diarrhea.
- Lung and brain hemorrhaging.
- Paralysis of the extremities.
- Diminution of growth (in subacute doses).

Humans:[5,11] - Acute-headache, dizziness, increased respiration, rapid pulse, nausea, vomiting, unconsciousness, convulsions, epigastric pains, emesis, coma, hypertension, hyperazotemia, hyperglycemia, albuminuria, increased lactate dehydrogenose level, absence of alkaline phosphatase in the cerebrospinal fluid, and death.

Chronic exposure-headache, anorexia, dizziness, weakness, and dermatitis.

Pigs: Acetronitrile administered to pregnant sows did not cause teratogenic effects.[12]

Regulatory Actions, Standards, Criteria, Recognition, Candidate Status for Specific Regulation

The American Conference of Governmental Industrial Hygienists (ACGIH) has recommended a tolerance limit value (TLV) of 40 ppm acetonitrile in air (about 70 mg/m^3).[13] According to Sax, the handling of acetonitrile is regulated by the Coast Guard, the Department of Transportation, and the International Air Transport Association.[14]

Acetonitrile References

1. Stecher, P.G., ed. 1968. The Merck Index. Merck and Co. Rahway, New Jersey.

2. U.S. Environmental Protection Agency. 1976. Oil and Hazardous Materials - Technical Assistance Data System: Printout on Acetonitrile. Washington, D.C.

3. Baron, R. L.. 1971. Toxicological Considerations of Metabolism of Carbonate Insecticides-Methomyl and Carbaryl. Pesticide Terminal Residues, Invited Paper In; p. 185-197.

4. Union Carbide Corp., Industrial Medicine and Toxicology Dept. 1965 Toxicology Studies, Acetonitrile New York.

5. Patty, F.A., ed.. 1963. Industrial Hygiene and Toxicology. Interscience Publishers, New York.

6. Spector, W.S.. 1956. Handbook of Toxicology-Volume 1. Saunders and Co. Philadelphia.

7. Chistensen, H.E., T.T. Luginbyhl (eds.). 1975. Registry and Toxic Effects of Chemical Substances. NIOSH Rockville, Md.

8. Hann, W. and P. Jensen. 1974. Water Quality Characteristics of Hazardous Materials. Texas A&M University.

9. McKee, Y.E. and H. W. Wolf (eds.). 1963. Water Quality Criteria. Resources Agency of California State Water Quality Control Board.

10. Haguenoer, J.M., J. Requidt, and M.C. Jacquemont. 1975. Experimental Acetonitrile Intoxications. J. Toxicol, Environment Hygiene 8 (2): 98-112

11. International Technical Information Institute. 1975. Toxic and Hazardous Ind. Chemicals Safety Manual.

12. Crowe, M.W.. 1973. Teratogenic capability of Tobacco (Nicotania Tobacum) and those chemicals commonly applied to the growing plant. Tobacco Health Workshop Conf., Proc., 4th. p. 198-202.

13. American Conf. of Gov. Ind. Hygienists. 1971. Documentation of the Threshold Limit Values for Substances in Workroom Air. 3rd edition.

14. Sax, N.I.. 1968. Dangerous Properties of Industrial Materials. Van Nostrand Reinhold and Company. New York.

Cyanide, Hydrogen Cyanide

Cyanide: The functional group - C≡N. It occurs as a solid when in the form of a salt or as an aqueous ion when dissolved. Dissolved cyanide is colorless and odorless.

Hydrogen cyanide (prussic acid, hydrocyanic acid; formonitrile): HCN. Liquid with faint bitter almond odor.

Natural Occurrence, Characteristics, and Associated Compounds

Cyanide is produced in minute quantities by some plants. It is widely used in industry primarily as sodium cyanide (NaCN) or hydrocyanic acid (HCN). Cyanides in various compounds are used in electroplating, steel plants, chemical plants, photographic processing, textile dying, ore processing, and insecticides. Of all the cyanides, hydrogen cyanide (HCN) is probably the most acutely lethal compound. HCN dissociates in water to hydrogen ions and cyanide ions in a pH dependent reaction. The cyanide ion is less acutely lethal than HCN. The relationship of pH to HCN shows that as the pH is lowered to below 7 less than 1% of the cyanide molecules are in the form of the CN ion and the rest are present as HCN. When the pH is increased to 8, 9, and 10, the percentage of cyanide present as CN ion is 6.7, 42, and 87%, respectively.

Physico-Chemical Properties

HCN: Molecular weight 27.04: melting point - 13.24°C: boiling point 25.7°C: vapor pressure 360 mm Hg at 7°C: flash point 18°C: autoignition point 37°C: lower explosive limit 6%, upper explosive limit 41%; lower flammability limit 6.0%. HCN is soluble in all proportions in water, alcohol, and ether. It forms a weakly acidic solution and may react with water, steam, acid, or acid fumes to produce highly toxic fumes of cyanide. Treatment with

caustic or hypochlorite converts cyanide to less toxic cyanates, but excessive application of treating agents can cause a new hazard. In addition, lime can be applied to help suppress evolution of HCN gas, and ferric (Fe^{+3}) salts may be added to precipitate the cyanide.[1]

In concentrated form, HCN polymerizes violently and spontaneously unless pure or stabilized.

Toxic Properties and Health Effects

Cyanide ion and hydrogen cyanide are very toxic to all organisms. Certain metals such as nickel may complex with cyanide to reduce toxicity, especially at higher pH values. On the other hand, zinc and cadmium cyanide complexes may be exceedingly toxic.

Toxicity data are given below.

a. Mammals

Compound	Animal	Route	Parameter	Dosage
CN	Mouse	Interperitoneal	LD_{50}	3mg/kg[2]
HCN	Human	Oral	LDL_0	0.57 mg/kg[1]
HCN	Human	Inhalation	LCL_0	5000 mg/m^3
HCN	Human	Inhalation	LCL_0	120 mg/m^3- 1 hr.[2]
HCN	Human	Inhalation	LC	200-480ppm - 30 min.[1]
HCN	Rat	Inhalation	LC_{50}	544 ppm - 5 min.[1]
HCN	Mouse	Inhalation	LC_{50}	169 ppm - 30 min.[1]
HCN	Mouse	Oral	LD_{50}	3.2 mg/kg[2]
HCN	Mouse	Interperitoneal	LD_{50}	2.99 mg/kg[2]
HCN	Mouse	Sub-cutaneous	LDL_0	3 mg/kg[2]
HCN	Mouse	Intravenous	LD_{50}	1.1 mg/kg[2]
HCN	Mouse	Intramuscular	LD_{50}	2.1 mg/kg[2]
HCN	Dog	Oral	LDL_0	4 mg/kg[1]
HCN	Dog	Inhalation	LC_{50}	300 ppm - 3 min.[1]
HCN	Dog	Sub-cutaneous	LDL_0	1.7 mg/kg[2]
HCN	Cat	Oral	LDL_0	2 mg/kg[2]
HCN	Cat	Inhalation	LCL_0	2500 mg/m^3 [2]
HCN	Cat	Sub-cutaneous	LDL_0	1.1 mg/kg[2]
HCN	Rabbit	Inhalation	LCL_0	600 mg/m^2-2 min.[1]
HCN	Rabbit	Interperitoneal	LD_{50}	1.57 mg/kg[2]
HCN	Rabbit	Sub-cutaneous	LD_{50}	2.5 mg/kg[2]
HCN	Rabbit	Sub-cutaneous	LD	1.1 - 3 mg/kg[2]
HCN	Rabbit	Intravenous	LD_{50}	820 mg/kg[2]
HCN	Rabbit	Intramuscular	LD_{50}	1.1 mg/kg[2]
HCN	Guinea Pig	Sub-cutaneous	LDL_0	0.1 mg/kg[2]

The high toxicity of hydrocyanic acid and the cyanides is due to their interference with the enzymes associated with cellular oxidation.[3] Oxygen can no longer be made available to the tissues, and death occurs through asphyxiation. On removal of cyanide from the tissues, normal function is restored provided that death has not already occurred.[3] In the body, the CN ion, except for a relatively small portion exhaled, is rapidly changed into a relatively non-toxic complex (thiocyanate) in the liver and eliminated in the urine. There is no evidence that cyanide or HCN is biologically accumulated.

The average fatal dose of HCN in humans is between 50 and 60 mg, and the limit for safe ingestion is estimated at 18 mg/day. Chronic exposure to mammals, as with all other animals, may produce fatigue and weakness. In acute cases, death is very quick; in less acute cases, symptoms are headache, dizziness, confusion, vertigo, a feeling of suffocation, and nausea.[3]

b. Fish*

Compound	Animal	Parameter	Conc. (mg/l)	Exposure (hrs)
HCN	Rainbow Trout	TL_m	0.07	24
HCN	Fish	Lethal	0.21	
HCN	Young bass	TL_m	0.16	72
HCN	Largemouth bass	Lethal	0.06	24
HCN	White crappie	Lethal	0.05-0.07	<24
HCN	Sunfish	Lethal	0.6	<24
HCN	Bluegill	TL_m	0.16	72
HCN	Bluegill	TL_{40}	0.155	72
HCN	Bluegill	Lethal	0.01-0.06	<24

*All data taken from reference 1.

b. Fish* (continued)

Compound	Animal	Parameter	Conc. (mg/l)	Exposure (hrs)
HCN	Bluegill	TL_m	0.18	96 (fish w acclim
HCN	Guppy	TL_m	0.42	20
HCN	Guppy	TL_m	0.28	30
HCN	Guppy	TL_m	0.26	43
CN	Pin Perch	TL_m	0.069	24

Cyanide is rated as highly toxic to aquatic life.[2] The chronic aquatic toxicity limit for CN and HCN is 0.05 mg/l. The toxicity of cyanides is also increased by increases in temperature and reductions in oxygen tensions. A temperature rise of 10°C produced a two to threefold increase in the rate of the lethal action of cyanide.

c. Aquatic and Marine Invertebrates, Bacteria, and Protozoa*

Compound	Animal	Parameter	Conc. (mg/l)	Exposure (hrs.)
HCN	Snail	TL_m	0.432	96
KCN	Prawn	LC_{50}	0.25	48
KCN	Cockle	LC_{50}	> 25	48
KCN	Crab	LC_{50}	> 5	48
CN^-	Activated Sludge 'Bugs'	Inhibition	4	
CN^-	Amoeba	Lethal	5×10^{-3}	

*All data taken from reference 1.

d. Plants

Compound	Plant	Parameter	Conc (mg/l)
CN^-	Eurasion watermilfoil	IL_{50} - root weight	22.4 [1]
CN^-	Eurasion watermilfoil	IL_{50} - steam weight	20 [1]
CN^-	Eurasion watermilfoil	IL_{50} - root length	28.6 [1]
CN^-	Eurasion watermilfoil	IL_{50} - stem length	27.3 [1]

The parameter IL_{50} refers to inhibition level, and is the concentration which causes a 50% reduction in the selected component. These are not lethal dosages. It should be noted that watermilfoil is a pollution tolerant plant that has congested some heavily polluted waterways (e.g., the Potomac River in the 1950's). It is likely that IL_{50} values for many other plants would be less than these reported for watermilfoil.

Regulatory Actions, Standards, Criteria, Recognition, Cardidate, Status for Specific Regulation

The recommended limit for cyanide concentration in drinking water is 0.2 mg/l.[1]

The I.C.C. classified HCN as a Class A poison. There are numerous restrictions on the transportation and handling.

Cyanide References

1. U.S. EPA. 1976. Oil and Hazardous Materials - Technical Assistance Data System: Printout on Hydrogen Cyanide. Washington, D.C.

2. Christensen, H.E., T.T. Luginbyhl (eds.). 1975. Registry of Toxic Effects of Chemical Substances. NIOSH. Rockville, Md.

3. Sax, N.I. 1968. Dangerous Properties of Industrial Materials. Van Nostrand Reinhold & Co., New York.

Lithium and its Compounds

Lithium metal - Li - soft, silverish metal with body-centered cubic crystals.

Lithium bromide - LiBr - white, cubic, deliquescent crystals or white to pinkish white granular powder.

Lithium hydroxide - LiOH - colorless tetrahedral crystals.

Lithium dithionite - $Li_2S_2O_4$ - analogous to $N_2S_2O_4$ which is light lemon-colored solid in powder or flake form or white to grayish-white crystalline powder.

Natural Occurrence, Characteristics, Associated Compounds

Lithium is widely distributed in small quantities throughout the earth's crust.[1] Reported background levels of lithium in mineral-rich soils range from 8 to 400 ppm.[2] Ivanov[3,4] and Ivanov and Muratova[5] analyzed lithium content in soils and found that more than 90 percent of all samples analyzed were in the 10 to 50 ppm range. Lithium is not known to be an essential plant nutrient.[1]

The major lithium compounds from the Li/organic electrolyte/SO_2 battery are LiOH (formed when Li metal combines with water), LiBr and $Li_2S_2O_4$. Since metallic lithium reacts quickly with water and aqueous ligands to form compounds, Versar concludes that toxicity from metallic lithium in the lithium/organic electrolyte/SO_2 battery does not represent an environmental hazard. The ensuing discussion of toxicity will therefore be concerned with lithium compounds.

Physico-Chemical Properties

Li - atomic weight 6.94 gm: melting point 179°C; boiling point, 1,317°C; density 0.535 @ 20°C. In moist air at room temperature, Li reacts exothermically with water vapor or nitrogen.[6] Li decomposes on contact with water or acids.

LiBr - molecular weight, 86.85: melting point 547°C: boiling point, 1,265°C: density 3.46 @ 25°C. LiBr is very soluble in water and greatly decreases vapor pressure over its solutions.[6] LiBr in hot concentrated solution dissolves cellulose.[6]

LiOH - molecular weight 23.95: melting point 450°C: boiling point - decomposes at 950°C: density 1.46. LiOH is formed when metallic Li is exposed to water. LiOH is slightly soluble in water (12.8 gm/100 ml @ 20°C).

$Li_2S_2O_4$ - molecular weight 135.06. $Li_2S_2O_4$ is soluble in cold water and decomposes in hot water. It has a high chemical oxygen demand and is readily oxidized.

Toxic Properties, Health Effects

The following quote appears in Industrial Hygiene and Toxicology, Vol. II:[7]

"Li can be relatively toxic to man and animals, a fact often unappreciated because its toxicity, dependent upon accumulation, is determined not only by the amount of Li given but on the amount of Na intake; the lower the Na intake, the more toxic is Li. Accordingly, statements on toxicity of Li are uninterpretable unless accompanied by statements on the Na intake."

Unfortunately, most of the toxicity studies done on lithium do not include statements on Na^+ intake.

Little work has been done on the toxicity of LiBr, LiOH and $Li_2S_2O_4$. Toxicity data for these compounds, NaOH, which is analogous to LiOH, and LiCl and NaBr, analogs of LiBr, are presented below.

a) Mammals

Compound	Animal	Route	Parameter	Dosage
LiCl	Dogs	Oral or sub-cutaneous	LD_{100}	60 mg/kg/day[7]
LiCl	Cats	Oral or sub-cutaneous	LD_{100}	60 mg/kg/day[7]
LiCl	Rat	Oral	LD_{50}	757 mg/kg[8]
LiCl	Rabbit	Oral	LD_{90}	850 mg/kg[9]
LiCl	Mouse	Interperitoneal	LD_{50}	1,100 mg/kg[9]
LiCl	Mouse	Interperitoneal	LD_{50}	604 mg/kg[9]
LiCl	Rat	Parenteral	TDL_0	1,062 mg/kg pr (teratogenic a toxic effects
LiCl	Mouse	scu	LDL_0	480 mg/kg[9]
NaBr	Rat	Oral	LD_{50}	3,500 mg/kg[9]
NaBr	Mouse	scu	LD_{50}	5,020 mg/kg[9]
NaBr	Rabbit	Oral	LDL_0	580 mg/kg[9]
NaOH	Rabbit	Oral	LDL_0	500 mg/kg[9]
NaOH	Mouse	Interperitoneal	LD_{50}	40 mg/kg[9]

Samilov[10] studied the comparative toxicities of six lithium salts and found that their toxicities were similar whether administered orally or through the skin. To mice, the order of toxicity from most toxic to least toxic was Li_2CO_3, LiCl, Li_2SO_4, LiBenzoate, Li Lactate, and LiBr.

In mammals, Li primarily affects renal and gastrointestinal function due to disturbed blood electrolyte balance. Symptoms of Li poisoning related to the kidney are anorexia, extreme weight loss, general weakness an fatigue, dehydration, thirst, and in animals other than man, reduced body temperature.[7] Gastrointenstinal disorders resulting from lithium toxicit are salivation, nausea, vomiting, and diarrhea.[7] Lithium may also cause the following nervous system disorders: fine tremor of hands, sometimes lips and jaws; more severe poisoning may cause muscular weakness, ataxia, positive Romberg sign, giddiness, tinnitis, drowsiness, slurred speech, ar blurred vision; in more advanced cases, hyperactive deep reflexes, muscula

hyperirritability, muscular fasciculations; in most severe cases, coma and epileptic seizures.[7]

Li has more effect on the central nervous system in man than in other animals. LiBr has been used as a hypnotic and sedative.[11] LiCl, formerly used as a table salt substitute, and Li_2CO_3 are used in the management of manic depressive psychosis.[11]

In one instance, a manic depressive psychotic attempted suicide by ingesting 22.5 gm of lithium carbonate (4.2 gm Li^+), and survived, showing only symptoms of gastrointestinal stress.[12] However, cases of chronic lithium poisoning from smaller amounts of lithium have been reported in humans, and most of these chronic cases showed central nervous system toxicity.

There is a negative correlation between Li content in drinking water and ischemic heart disease. Blachly[13] suggests that the higher death rate from cardiovascular disease in soft-water areas may be due to a lack of Li, speculating that its effect on catecholemine metabolism may be the beneficial agent.

LiOH is very caustic and resembles NaOH in effect, being very corrosive when contacted or ingested. LiOH apparently caused lesions of the forepaws and nose in mice, rats, rabbits and guinea pigs.[7] It has been used to absorb CO_2 from air in space capsules, and on one occasion an unintended dispersal of the LiOH powder caused much irritation of the eyes and respiratory tract of astronauts.[14]

$Li_2S_2O_4$ forms a slightly alkaline bisulfate solution in water. When heated to decomposition $Li_2S_2O_4$ emits toxic vapors. In the environment, $Li_2S_2O_4$ is readily oxidized to bisulfite and then bisulfate. Sodium dithionite, which is very closely related to lithium dithionite, has a chronic animal toxicity limit of 1,000 ppm.[15] This limit is due to the toxicity of sodium, so apparently the dithionite radical is not particularly toxic.

b) Fish

Compound	Animal	Parameter	Conc. (mg/l)	Exposure
LiCl	Goldfish	Lethal	3,750	22 to 27 hrs.[16]
LiCl	Mature small freshwater fish	Lethal	2,600	24 hrs.[16]
LiCl	Freshwater fish	Lethal	1,950-3,770	24 hrs.[16]

c) Freshwater invertebrates, protozoa, and bacteria

Compound	Animal	Parameter	Conc. (mg/l)	Exposure
LiCl	*Daphnia magna*	Immobilization	<7.2[16]	
LiCl	*Daphnia magna*	Poison threshold	16 mg/l	48 hrs.[16]
LiCl	*Scenedesmus* (bact.)	No toxic effect	1,000 mg/l[16]	
LiCl	*Escherichia coli* (bact.)	No toxic effect	1,000 mg/l[16]	
LiCl	*Microregna* (prot.)	Food intake inhibition	66 mg/l[16]	
LiCl	Water beetle	Excitation	19,500 mg/l[16]	
LiCl	Fly larvae	Toxic effect	848 mg/l[16]	

d) Plants

Although Li is not known to be an essential plant nutrient, when very dilute solutions of lithium salt are added to lithium poor soil, growth of wheat, barley, sugar cane, yeast, radishes and carnations is stimulated. Larger concentrations of Li are toxic to plants. Voelker[17] found that any Li salt is toxic in amounts greater than 30 ppm and stimulating in amounts less than 20 ppm.

Plants which have been reported to exhibit Li toxicity are soybean, tomato, white mustard, marijuana, sunflower, flax, vetch, corn, celery, citrus, olive, avocado and wheat. As most of the experiments on Li toxicity

to plants were done before 1945, few report LD_{50} or other standard toxicological measures.

Citrus is very susceptible to injury from Li compounds and may indicate Li excess.

Regulatory Actions, Standards, Criteria, Recognition, Candidate Status for Specific Regulation

The EPA has proposed the following limits for Li^+ in irrigation water: max. 2.5 mg/l, avg. 0.075 mg/l.[16]

Hibbard recommends, without references, a limit of 5 mg/l Li^+ in water used for drinking or cooking.[18]

LITHIUM REFERENCES

[1] Bradford, G.R. 1966. Lithium In Diagnostic Criteria for Plants and Soil, ed. by H.D. Chapman.

[2] Swaine, D.J. 1955. The Trace-Element Content of Soils. Commonwealth of Bur. Soil Sci. Tech. Comm. No. 48. Herald Printing Works, York, England.

[3] Ivanov, D.N. 1954. The Content of Rare Alkali Elements in Soils. Pochvovedenie (Pedology) 1954 (2):32-45.

[4] Ivanov, D.N. 1956. Occurrence of Lithium, Rubidium, and Cesium in the Products of Contemporary Erosion and in Soils. Shornik Akad. Nauk S.S.S.R. 2:77-84.

[5] Ivanov, D.N. and V.S. Muratova. 1955. The Distribution of Lithium in Saline Soils. Trudy Pochvennogo Inst. Dokuchaeva Akad. Nawk S.S.S.R. 44:294-301.

[6] Hawley, G.G. 1971. The Condensed Chemical Dictionary. Van Nostrand Reinhold Co., New York.

[7] Patty, F.A. 1963. Industrial Hygiene and Toxicology - Vol. II - Toxicology. Interscience Publishers, New York.

[8] U.S. EPA. 1976. Oil and Hazardous Materials - Technical Assistance Data System: Printout on Lithium. Washington, D.C.

[9] Christensen, H.E., T.T. Luginbyhl (eds.). 1975. Registry of Toxic Effects of Chemical Substances. NIOSH. Rockville, Md.

[10] Samoilov, N.N. 1970. Comparative Toxicity of Some Lithium Salts. Farmakol. Toksikol. (Moscow). Vol. 33, Issue 5, p. 616-619.

[11] Gosselin, R.E., H.C. Hodge, R.P. Smith, M.N. Gleason. 1976. Clinical Toxicology of Commercial Products - Acute Poisoning. Williams & Wilkins Co., Baltimore.

[12] Horowitz, L.C. and G.U. Fisher. 1969. Acute Lithium Toxicity. New England Journal of Medicine. 281(24):1369.

[13] Blachly, P.L. 1969. Lithium Content of Drinking Water and Ischemic Heart Disease. New England Journal of Med. 281(21):682.

[14] Grant, W.M. 1974. Toxicology of the Eye. Charles C. Thomas. Springfield, Ill.

[15] U.S. EPA. 1976. Oil and Hazardous Materials - Technical Assistance Data System Printout on Sodium Hydrosulfite. Washington, D.C.

[16] McKee, Y.E. and H.W. Wolf (eds.). 1963. Water Quality Criteria. Resources Agency of Cal. State Water Qual. Control Board.

[17] Voelker, J.A. 1912. Pot-Culture Experiments. (1910-11-12). J. Royal Agr. Soc. (England) 73:314-338.

[18] Hibbard, P.L. 1934. The Significance of Mineral Matter in Water. J.A.W.W.A. 21:884.

Propylene Carbonate

Propylene carbonate: $C_3H_6CO_3$. Colorless, odorless liquid.

Natural Occurrence, Characteristics, Associated Compounds

Propylene carbonate is not known to occur naturally.

Industrial uses include solvent extraction, organic synthesis, purification of natural gases and as a plasticizer and solvent for spinning synthetic fibers. It has also been used as a base for cosmetics.

Propylene carbonate is a cyclic compound, with 3 carbon atoms and 2 oxygen atoms forming the ring.

Physico-Chemical Properties:

Molecular weight 102.09 gm: melting point -49.2°C: boiling point 241.7°C: refractive index 1.4209 @ 20°C: specific gravity 1.206 gm/ml. Slightly soluble in water. Flammable (flash point 132°C).

Toxic Properties, Health Effects

A number of studies have shown that propylene carbonate is practically non-toxic to mammals. Data on the toxicity of propylene carbonate to other organisms was not available.

Acute mammalian toxicity data are given below:

Animal	Route	Parameter	Dosage
Mouse (albino)	oral	LD_{50}	20.7 gm/kg[1]
Mouse	scu	LD_{50}	15.8 ml/kg[2]
Rat	scu	LD_{50}	11.1 ml/kg[2]
Rat	oral	LD_{50}	29.1 ml/kg[3]
Rabbit	scu	LD_{50}	20 ml/kg[3]

Subacute mammalian toxicity data are given below.

1. Rabbits exposed to single doses of 1 ml/kg of undiluted compound applied directly to abdomenal skin showed no irritation after 22 hours.[1]

2. Rabbits receiving skin applications of 1 ml/kg, 5 days per week for 2 weeks exhibited no signs of irritation.[1]

3. Guinea Pigs exhibited no signs of skin sensitization based on investigations with a modified Landsteiner technique.[1]

4. Rabbits exposed to .05 ml of undiluted compound into eyes manifested marked erythema of the conjunctiva, vascularization of the sclera and edema of the lids and nictitating membrane over first 24 hours. A dull film persisted for 4 days in one case. All eyes cleared by the 7th day.[1]

5. Various animals (dogs, guinea pigs, rats) exposed a total of 15 times to an aerosol of propylene carbonate over 21 days (six hours per day, 5 days per week) showed no significant signs of toxicity other than rhinorrhea and diarrhea in rats. Compound concentration was 2.8 mg/l.[1]

6. Rats fed diets containing 1% and 3% compound for 13 weeks exhibited no evidence of intoxication.[1]

7. Rats exposed to concentrated vapor for 8 hours all survived.[4]

8. Saline solutions containing 3.5%, 10.5%, and 17.5% of propylene carbonate injected in the clipped backs of rabbits caused increase of basal cells, keratinization and hyperkeratosis. Compared to control animals, there was no difference in weight gain, food and water intake, urinalysis, plasma analysis, hematology and weight of organs.[2]

In summary, propylene carbonate is only slightly toxic to mammals. Its effects on other organisms are not known.

Regulatory Actions, Standards, Criteria, Recognition, Candidate Status for Specific Regulation

There are no specific regulations regarding discharge of propylene carbonate.

Propylene Carbonate References

[1] Jefferson Chemical Co., Inc. 1962. Propylene Carbonate Toxicity Data. Houston, TX.

[2] Kuramoto, M., A. Kimura, Y. Ishimura, T. Hamamoto and W.J. Lee. 1972. Acute subcutaneous toxicity and subacute dermal toxicity studies of hexanetriol and propylene carbonate. Shikoku Acta Med. 28 (2) p.276-283.

[3] Union Carbide Corp. 1958. Toxicology Studies - Propylene Carbonate. Ind. Med. and Toxicology Dept. New York, N.Y.

[4] Patty, F.A. (ed) 1963. Ind. Hygiene and Toxicology. Interscience Publishers, New York.

Sulfur Dioxide, Sulfurous Acid

Sulfur dioxide: SO_2 (sulfurous acid anhydride, sulfurous oxide). Colorless gas or liquid with pungent odor.

Sulfurous acid: H_2SO_3 (sulfur dioxide solution). Colorless liquid. Suffocating sulfur odor.

Natural Occurence, Characteristics, Associated Compounds

SO_2 occurs naturally from the combustion of organic materials (e.g. resulting from forest fires). Since it reacts readily with H_2O to form H_2SO_3 its occurence in nature is transient. SO_2 is an important constituent of smog, resulting from the combustion of fossil fuels. In some areas with severe air pollution, it has been implicated in the trend of increasing acidity of rain.

SO_2 is extremely irritating, and is easily detectable by humans in concentrations as low as 3 ppm.

It is used commercially as a fumigant, insecticide, and fungicide. H_2SO_3 is gradually oxidized to sulfuric acid in nature. The SO_4 radical (sulfate) is found in appreciable amounts in most water and soil systems.

Physico-Chemical Properties:

SO_2: Molecular weight 64.06: melting point -75.5°C: boiling point -10.0°C: vapor pressure 2,538 mm @ 21.1°C. Combines with water to form H_2SO_3. Non-flammable.

H_2SO_3: Molecular weight 82.08: density 1.03. When heated to decomposition, H_2SO_3 emits SO_2.

Toxic Properties, Health Effects

SO_2 and H_2SO_3 are known to have toxic effects on a variety of organisms.

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Mammals

Species	Compound	Route	Parameter	Dosage
Human	SO_2	Inh.	TCL_0	4 ppm[1]
Rat	SO_2	Inh.	LCL_0	1,000 ppm[1]
Rat	SO_2	Inh.	LC_{100}- 20min.	993 ppm[1]
Rat	SO_2	Inh.	LC_{100}-5 hr.	611 ppm[1]
Mouse	SO_2	Inh.	LC_{100} 20 min.	764 ppm[1]
Guinea Pig	SO_2	Inh.	LCL_0-5 min.	5,000 ppm[2]
Human	SO_2	Inh.	TCL_0-5 days	3 ppm[2]
Human	SO_2	Inh.	TDL_0-5 mins.	10 ppm[2]

Subacute effects of SO_2 on mammals include the following:

1. Hamsters and rats tolerated 50 ppm SO_2 for 23 hours/day for up to 32 days showing ciliary inhibition and temporary loss of body weight.[3]

2. Mice continuously exposed to 40 ppm SO_2 showed depressed feed and water intake, body weight and O_2 consumption. Upper respiratory damage was caused.[4]

3. Human subjects exposed to 113 ppm for 10-30 minutes showed increased pulmonary flow resistance.[5]

SO_2 harms mammals primarily through contact with the lungs, although it also is harmful when in contact with moist skin. It is not metabolized - its effect is physico-chemical. In contact with moist areas, it forms sulfurous acid which physically damages tissue, especially the mucosa in the lung. SO_2 is not known to have any chronic systemic effects.

Sulfurous acid is corrosive to skin due to its highly acidic nature. It can cause lesions and other damage on contact with skin.

Fish

Species	Compound	Parameter	Concentration
Sunfish	SO_2	Lethal - 1 hr.	16 mg/l[1]
Sunfish	SO_2	Lethal	16-19 mg/l[1]
Trout	SO_2	Immobilized-10 min.	10 mg/l[1]
Trout	SO_2	Lethal - 1 hr.	5 mg/l[6]
Fish	H_2SO_3	Lethal	0.5 mg/l[6]
Tench	H_2SO_3	Lethal-2 hr.	1 mg/l[6]

Unfortunately, in the studies above the hardness of the water was not given. In hard, well-buffered water systems, the quantity of aqueous SO_2 and H_2SO_3 needed to lower the pH (make the water more acidic) is considerably greater than in soft-water systems. If these studies were done in distilled water, a small amount of H_2SO_3 would lower the pH considerably. Fish are very susceptible to sudden changes in pH, and most cannot withstand pH below 3.5-4.5. The toxicity of SO_2-H_2SO_3 in the above studies was apparently due to the lowering of the pH.

Plants

SO_2 is extremely toxic to plants. It interferes with pollination in some plants[7] and decreases photosynthesis by inhibiting the activity of photosynthetic enzymes.[8] It also causes visible damage to plant tissue. Marginal and intercostal necrosis results from exposure to low concentrations of SO_2 (less than 1 ppm). Plants reported to exhibit toxic reactions to SO_2 include: pimento, radish, tomato, cucumber, turnip, chinese cabbage, cabbage, lettuce, eggplant, spinach, Populus deltoides, Pinus resinosa, Pinus nigra, and Pisea pungeus.

SO_2 in smog has damaged forests as far as 75 miles away from Los Angeles.

H_2SO_3 can cause lesions on plant tissue. Acidification of the soil by H_2SO_3 may exceed the tolerance limits of indigenous plants, allowing acid-tolerant plants to invade the area.

Regulatory Actions, Standards, Criteria, Recognition, Candidate Status for Specific Regulation

The American Congress of Governmental Industrial Hygienists (ACGIH) has recommended a tolerance limit value for SO_2 of 5 ppm in air (13 mg/m^3 air).

Sax[9] states that 50 to 100 ppm is considered to be the maximum concentration permissible for 30 to 60 minutes and 400 to 500 ppm is immediately dangerous to life.

SO_2 emission is regulated by the Clear Air Act. The National Primary Ambient Air Quality Standards for sulfur oxides, measured as SO_2, are: annual arithmetic mean - 80 $\mu gm/m^3$ (0.03 ppm); maximum 24-hour concentration not to be exceeded more than once per year - 365 $\mu gm/m^3$ (0.14 ppm).

Fossil-fuel fired steam generating units are limited to discharge of SO_2 such that the maximum 2-hour average for liquid fossil fuel shall not exceed 0.80 lb./million BTU heat input (1.4 gm./million calories) and the maximum 2-hour average for solid fossil fuel shall not exceed 1.2 lb./ million BTU heat input (2.2 gm./million cal.).

Sulfuric acid production plants are limited to a 2-hour discharge of SO_2 not in excess of 4 lbs./ton of acid produced (2 kg./metric ton).

SO_2 and sulfite, the dissociated form of H_2SO_3, are registered pesticides and their use and handling is covered by regulations promulgated by the EPA's Office of Pesticide Programs.

SULFUR DIOXIDE, SULFUROUS ACID REFERENCES

[1] U.S. EPA. 1976. Oil and Hazardous Materials - Technical Assistance Data System: Printout on SO_2. Washington, D.C.

[2] Christensen, H.E., T.T. Luginbyhl (eds.). 1975. Registry of Toxic Effects of Chemical Substances. NIOSH. Rockville, Md.

[3] Battigelli, M.C. and D.A. Fraser. 1971. The Long Term Effects of Sulfur Dioxide on Ciliary Activity of the Trachea and Microflora of the Respiratory Tract of Rodents.

[4] Jolinson, H.D., E.M. Lincoln, and R.E. Flatt. 1972. Sulfur Dioxide Exposure and Recovery Effects on Mice. Proceedings of the Soc. of Biological Medicine. 139(3):p. 861-864.

[5] Frank, N.R. et al. 1962. Effects of Acute Controlled Exposure to SO_2 on Respiratory Mecahnics in Healthy Male Adults. J. Applied Physiology. Vol. 17, P. 252.

[6] McKee, Y.E. and H.W. Wolf (eds.). 1963. Water Quality Criteria. Resources Agency of Cal. State Water Qual. Control Board.

[7] Karnosky, D.F. and G.R. Stairs. 1974. The Effects of SO_2 on in vitro Forest Tree Pollen Germination and Tube Elongation. J. Env. Qual. 3(4):406-409.

[8] Tanaka, H., T. Takanashi, and M. Yatazawa. 1974. Experimental Studies on SO_2 Injuries in Plants. Water Air Soil Pollution 3(1):11-16.

[9] Sax, N.I. 1968. Dangerous Properties of Industrial Materials. Van Nostrand Reinhold & Co., New York.

GLOSSARY OF TOXICITY TERMS AND SYMBOLS

Toxicity terms and symbols used in Appendix A fall under two categories: Toxicity parameters and routes of administration. The glossary is divided into these two topics. Since all toxicity data were reported as they appear in the original reference, several equivalent parameters are used (e.g. MLD = LD_{50}).

<u>Toxicity Parameters</u>

IL_{50} - Inhibition level, the concentration causing a 50% reduction in some characteristic such as stem or root length.

LCL_0 - Lowest published lethal concentration.

LDL_0 - Lowest published lethal dosage

LC_x - Lethal concentration, x percent kill (e.g. LC_{50} is the concentration that will kill 50% of the test population).

LD_x - Lethal dose, x percent kill (e.g. LD_{50} is the dose that will kill 50% of the test population).

MLD - Mean lethal dose (same as LD_{50}).

TCL_0 - Lowest published toxic concentration.

TDL_0 - Lowest published toxic dose

TL_m - Median toxic level.

TL_x - Toxic level, x percent affected.

ROUTES OF ADMINISTRATION

Interperitoneal (ipr) - administration into the peritoneal cavity

Inhalation (inh) - breathing (gases)

Intramuscular (im) - administration into the muscle by hypodermic needle

Intravenous - administration directly into the vein by hypodermic needle

Oral - via the mouth (solids or liquids)

Parenteral - administration into the body via the skin. Reference not specific as to whether it is sub-cutaneous, intramuscular, intravenous, etc.

Skin - application to the intact skin

Sub-cutaneous (scu) - administration under the skin

APPENDIX B

State Legislation

State regulations were examined for three major provisions:

1. Provision for the promulgation of guidelines for solid waste disposal;
2. Granting enforcement authority to agencies and outlining the powers and duties of the agencies. Prescription of penalties for violation; and
3. Establishment of solid waste management regulations.

The following table lists pertinent state legislation and indicates which of the above points are covered by each law.

State	Title	Act No. and/or Effective Date	Major Provisions
Alabama	Solid Waste Disposal Act	Act 77, 1969 Amended by Act No. 2247, 1971	1,2
	Solid Waste Management Regulations	Effective July 19, 1972	3
	Alabama Standards for disposal of solid wastes	June 18, 1969	3
Alaska	Alaska Department of Environmental Conservation Act	Laws of Alaska Title 46 July 1, 1971	1,2
	Alaska Solid Waste Management Regulations	July 19, 1973	3
Arizona	Arizona Solid Waste Rules	Not given	3
Arkansas	Arkansas Solid Waste Management Act	Act 237, 1971	1,2
	Arkansas Solid Waste Disposal regulations	June 28, 1973	3
California	California Solid Waste Management and Resource recovery Act of 1972	September 18,1973	1,2
	California Hazardous Waste Control Act	July 1, 1973	1,2
Colorado	Colorado Solid Waste disposal Sites and Facilities law	April 19, 1976	2
	Colorado Solid Waste Regulations	April 1, 1972	3
Connecticut	Connecticut Solid Waste Management Act	October 1974	1,2
	Connecticut Solid Waste Management Regulations	Jan. 10, 1975	3

State	Title	Act No. and/or Effective Date	Major Provisions
Delaware	Delaware Solid Waste Authority Act	Aug. 12, 1975	2
	Delaware Solid Waste Disposal regulation	Aug. 29, 1974	3
Florida	Florida Resource Recovery & Management Act	Not given	1,2
	Florida resource recovery and management regulations	April 15, 1975	3
Georgia	Georgia Solid Waste Management Act	Act 486, April 5, 1972	1,2
	Georgia Solid Waste Management Rules	Dec. 12, 1972	3
Hawaii	Hawaii Environmental Quality Law	May 22, 1972	1,2
	Hawaii Solid Waste Management Control Regulations	July 30, 1974	3
Idaho	Idaho Solid Waste Law	1972	1,2
	Idaho Solid Waste Regulations and Standards	June 28, 1973	3
Illinois	Illinois Environmental Protection Act	1970	1,2
	Illinois Solid Waste Regulations	July 19, 1973	3

State	Title	Act No. and/or Effective Date	Major Provisions
Illinois (continued)	Amendments to the Environmental Protection Act	April 12, 1975	1
Indiana	Indiana Refuse Disposal Act	1965	1,2
	Indiana Solid Waste Management Permit regulations	Aug. 15, 1974	3
Iowa	Iowa Department of Environmental Quality Act, Part 1, Solid Waste	Jan. 1, 1973	1,2
Kansas	Kansas Solid Waste Law	July 1, 1974	1,2
	Kansas Solid Waste Disposal Act	April 10, 1973	1,2
	Kansas Solid Waste Management Standards and regulations	Jan. 1, 1972	3
Kentucky	Kentucky garbage and refuse disposal law	June 1, 1966	1,2
	Kentucky Solid Waste Regulations	June 11, 1975	3
Louisiana	Louisiana Solid Waste Regulations	Jan. 26, 1968	3

State	Title	Act No. and/or Effective Date	Major Provisions
Maine	Maine Solid Waste Management Act	Oct. 3, 1973	1,2
	Maine Solid Waste Management Regulations	July 1, 1975	3
Maryland	Maryland Solid Waste Laws	Not given	1,2
	Maryland Solid Waste Regulations	Jan. 1971	3
	Maryland Hazardous Substances Disposal Act	May 17, 1976	1,2,3
Massachusetts	Massachusetts Solid Waste Disposal Law	Nov. 27, 1970	1,2
	Massachusetts Sanitary Landfill regulations	April 21, 1971	3
Michigan	Michigan Solid Waste Disposal Act	Act. 87 June 28, 1965	1,2
	Michigan Solid Waste Regulations		1,2
Minnesota	Minnesota Solid Waste Recycling Law	July 1, 1974	1,2
	Minnesota Solid Waste Disposal Regulations	Sept. 26, 1973	3
	Minnesota Hazardous Waste Act	1974	1,2

State	Title	Act No. and/or Effective Date	Major Provisions
Mississippi	Mississippi Solid Waste Disposal Act of 1974	April 24, 1974	1,2
	Mississippi Solid Waste Regulation	Not given	3
Missouri	Missouri Solid Waste Law	July 30, 1975	1,2
	Missouri Refuse Disposal Regulations	Not given	3
	Missouri Waste Rules and Regulations	Dec. 11, 1973	3
Montana	Montana Refuse Disposal Control Law	Not given	1,2
	Montana Refuse Disposal District Law	1973	2
Nebraska	Nebraska Solid Waste Management Rules	June 25, 1975	3
	Nebraska Solid Waste Disposal Sites Law	Mar. 6, 1972	2
	Nebraska Solid Waste Control Rules	July 6, 1972	3

State	Title	Act No. and/or Effective Date	Major Provisions
Nevada	Nevada Solid Waste Disposal Law	Not given	1,2
	Nevada Solid Waste Management Regulations		3
New Hampshire	New Hampshire Waste Disposal Laws	Mar. 1972	1,2
New Jersey	New Jersey Solid Waste Laws	Dec. 6, 1970	1,2
	New Jersey Waste Control Law	Jan. 2, 1974	2
	New Jersey Solid Waste Management Regulations	July 1, 1974	3
New Mexico	New Mexico Solid Waste Management Regulations	June 3, 1974	3
New York	New York Environmental Conservation Law - Solid Waste	Sept. 1, 1975	1,2
	New York Refuse Disposal Rules	Sept. 1, 1973	3
North Carolina	North Carolina Solid Waste Disposal Law	1969	2
	North Carolina Solid Waste Disposal Regulations	Mar. 11, 1971	3

State	Title	Act No. and/or Effective Date	Major Provisions
North Dakota	North Dakota Solid Waste Management and Land Protection Act	July 1, 1975	2
	North Dakota Solid Waste Management Regulations	Not given	3
Ohio	Ohio Solid Waste Disposal Law	Not given	1,2
	Ohio Solid Waste Disposal Regulations	July, 1968	3
Oklahoma	Oklahoma Solid Waste Management Act	1971	1,2
	Oklahoma Solid Waste Management Regulations	June 13, 1971	3
	Oklahoma Controlled Industrial Waste Disposal Act	1976	1,2,3
Oregon	Oregon Solid Waste Management Law - Environmental Hazardous Waste Chapter	1973	1,2
	Oregon Solid Waste Regulations	Dec. 17, 1971	3
	Oregon Solid Waste Management Regulations	April 5, 1972	2,3

State	Title	Act No. and/or Effective Date	Major Provisions
Pennsylvania	Pennsylvania Solid Waste Management Act	July 31, 1968	1,2
	Pennsylvania Solid Waste Regulations	Aug. 2, 1971	3
Rhode Island	Rhode Island Solid Waste Law	July 1, 1974	1,2
	Rhode Island Solid Waste Management Regulations	Mar. 16, 1975	3
South Carolina	South Carolina Industrial Solid Waste Disposal Site Regulation	Mar. 16, 1972	3
	South Carolina Guidelines for Waste Disposal Permits	Feb. 14, 1973	3
South Dakota	South Dakota Solid Waste Disposal Act	July 1, 1972	1,2
	South Dakota Solid Waste Rules	Feb. 20, 1974	1,2
Tennessee	Tennessee Solid Waste Disposal Act	Not given	1,2
	Tennessee Solid Waste Regulations	Jan. 20, 1971	3

State	Title	Act No. and/or Effective Date	Major Provisions
Texas	Texas Solid Waste Disposal Act	1969	1,2
	Texas Solid Waste Regulations	Nov. 5, 1970	3
	Texas Regulations on Industrial Solid Waste Management	Dec. 31, 1975	3
Utah	Solid Waste Disposal Regulations	July 17, 1974	2,3
Vermont	Vermont Solid Waste Law	Not given	1,2
	Vermont Solid Waste Regulations	April 17, 1969	3
Virginia	Virginia Solid Waste Disposal Law	1974	1,2
	Virginia Solid Waste Regulations	Apr. 11, 1971	3
Washington	Washington Solid Waste Management Law	Not given	1,2
	Washington Hazardous Waste Act	1976	1,2,3

State	Title	Act No. and/or Effective Date	Major Provisions
W. Virginia	W. Virginia Solid Waste Laws	July 13,1973	1,2
	W. Virginia Solid Waste Regulations	July 1, 1974	3
Wisconsin	Wisconsin Solid Waste Disposal Law	1967	1,2
	Wisconsin Solid Waste Management Rules	July 1, 1973	3
Wyoming	Wyoming Solid Waste Law	1973	1,2
	Wyoming Solid Waste Management Rules	Dec. 22, 1975	3

APPENDIX C

Laboratory Verification

C-1 Analytical Methods

pH

All pH determinations were performed with Orion Ionalyzer model 407 with Calomel reference electrode and pH electrode.

Conductivity

Conductivity was determined by use of YSI S-C-T meter model 33.

Lithium

All analyses done by Atomic Absorption on samples diluted 1:1000.

Sulfite

All analyses followed Technicon Auto Analyzer II Industrial Method No. 173-72W.

Cyanide

The Auto Analyzer II Industrial Method No. 315-74W (excluding UV digestion) was used for cyanide analyses. To compare the accuracy of the Auto Analyzer II method to EPA accepted procedures (Standard Methods, 14th ed. pp. 365-72), split samples were run by both methods. Comparison between results given below indicates a maximum difference of eight percent at concentrations greater than 20 mg/l. In the range of the detection limit for the EPA technique, two samples measured higher cyanide in Auto Analyzer method. Five other samples in this range were consistent for both methods.

Sample	Auto Analyzer mg/l cyanide	EPA Approved mg/l cyanide
Live I - 24 hours	0.094	< 0.10
Live I - 72 hours	0.094	< 0.10
Live I - 144 hours	0.088	< 0.10
Discharged I - 24 hours	43.0	41.0
Discharged I - 72 hours	39.0	39.0
Discharged I - 144 hours	28.0	26.0
Live II - 4 hours	0.087	< 0.10
Live II - 24 hours	0.064	< 0.10

Sample	Auto Analyzer mg/l cyanide	EPA Approved mg/l cyanide
Live II - 72 hours	0.146	< 0.10
Live II - 144 hours	0.128	< 0.10
Discharged II - 4 hours	32	31
Discharged II - 24 hours	33	32
Discharged II - 72 hours	29	31
Discharged II - 144 hours	25	23

C-2 Laboratory Results

All results are presented in following tables:

Phase 1	Table C-1
Phase 2	
Discharged cells	Table C-2
Live cells	Table C-3
Controls	Table C-4
Phase 3	
Lakeland Discharged	Table C-5
Lakeland Live	Table C-6
Lakeland Control	Table C-7
Mattapeake Discharged	Table C-8
Mattapeake Live	Table C-9
Mattapeake Control	Table C-10
Hagerstown Discharged	Table C-11
Hagerstown Live	Table C-12
Hagerstown Control	Table C-13
Soil Characterization	Table C-14
Flow Log	Table C-15

TABLE C-1

LITHIUM BATTERY DISPOSAL - PHASE I

DISCHARGED BATTERY I	4hr	24hrs	72hrs	144hrs	COMMENTS
pH	11.90	11.70	11.10	10.60	
Conductivity - µmhos	6400	5200	5600	5500	
Temperature - C°	23.0	24.0	24.0	23.8	
Lithium - mg/l	352.6	366.1	481	1076	
Sulfite - mg/l	1080	660	1560	1080	
Cyanide - mg/l	34	41	39	26	
DISCHARGED BATTERY II					
pH	11.60	11.50	10.85	8.90	
Conductivity - µmhos	5100	3200	4100	5600	
Temperature - C°	22.5	26.0	24.0	24.0	
Lithium - mg/l	339	257.6	380	891	
Sulfite - mg/l	360	480	1260	2100	
Cyanide - mg/l	31	32	31	23	
LIVE BATTERY I					
pH	6.4	6.7	6.9	10.3	
Conductivity - µmhos	3000	3800	6100	6400	
Temperature - C°	21.6	22.3	24.0	23.8	
Lithium - mg/l	474.6	515.3	721	798	
Sulfite - mg/l	1730	2050	1950	2350	
Cyanide - mg/l	< 0.10	< 0.10	< 0.10	< 0.10	
LIVE BATTERY II					
pH	11.2	11.7	11.4	10.4	
Conductivity - µmhos	8400	6300	7000	6200	- Slight Flaming During Opening
Temperature - C°	21.6	23.0	24.0	24.0	
Lithium - mg/l	657.7	728.5	698	791	
Sulfite - mg/l	1980	2420	5520	4680	
Cyanide - mg/l	< 0.10	< 0.10	< 0.10	< 0.10	

TABLE C-2

LITHIUM BATTERY DISPOSAL - PHASE II - DEAD BATTERIES

DISCHARGED - INITIAL	4hrs	24hrs	72hrs	168hrs	COMMENTS
pH	3.95				
Conductivity - µmhos	5900				
Temperature - C°	21.3	NA	NA	NA	
Lithium - mg/l	496				
Sulfite - mg/l	< 0.03				
Cyanide - mg/l	1.3				
DISCHARGED - L					
pH	4.30	4.25	4.13		Sample lost due to broken Flask 72 hrs after Sample Taken.
Conductivity - µmhos	2200	2230	3230		
Temperature - C°			22.7		
Lithium - mg/l	473	488	481	-	
Sulfite - mg/l	0.96	0.28	0.67		
Cyanide - mg/l	0.19	2.6	1.1		
DISCHARGED - M					
pH	4.30	4.70	4.20	4.75	
Conductivity - µmhos	1980	1840	2870	3400	
Temperature - C°			24.0	228	
Lithium - mg/l	442	388	403	295	
Sulfite - mg/l	0.66	0.86	0.45	0.09	
Cyanide - mg/l	1.8	1.6	1.6	.15	
DISCHARGED - H					
pH	5.20	5.89	5.52	6.70	
Conductivity - µmhos	2040	2130	2970	4300	
Temperature - C°			23.4	22.6	
Lithium - mg/l	434	426	426	465	
Sulfite - mg/l	0.63	0.35	0.98	0.15	
Cyanide - mg/l	0.20	0.18	2.0	1.3	

TABLE C-3

LITHIUM BATTERY DISPOSAL - PHASE II - LIVE BATTERIES

	4hrs	24hrs	72hrs	168hrs	COMMENTS
LIVE - INITIAL					
pH	6.50				
Conductivity - μmhos	6800				
Temperature - C°	19.8				
Lithium - mg/l	713				
Sulfite - mg/l	< 0.03				
Cyanide - mg/l	< 0.10				
LIVE - L					
pH	5.68	5.71	5.15	5.27	
Conductivity -μmhos	2350	2730	3590	6100	
Temperature - C°			22.9	23.7	
Lithium - mg/l	651	674	659	667	
Sulfite - mg/l	0.34	0.39	0.30	0.20	
Cyanide - mg/l	< 0.10	< 0.10	<0.13	0.19	
LIVE - M					
pH	5.12	5.24	4.52	2.89	
Conductivity -μmhos	2010	2210	5500	5300	
Temperature - C°			22.9	23.4	
Lithium - mg/l	605	581	527	419	
Sulfite - mg/l	1.23	< 0.03	<0.03	0.15	
Cyanide - mg/l	< 0.10	< 0.10	<0.10	< 0.13	
LIVE - H					
pH	6.63	6.70	5.73	6.59	
Conductivity - μmhos	2300	2260	2420	4700	
Temperature - C°			23.8	24.1	
Lithium - mg/l	581	574	581	442	
Sulfite - mg/l	0.81	< 0.03	0.08	0.84	
Cyanide - mg/l	< 0.10	0.15	0.44	0.13	

TABLE C-4

LITHIUM BATTERY DISPOSAL - PHASE II - CONTROLS

BLANK - LAKELAND	24hrs	72hrs	COMMENTS
pH	4.48	5.00	
Conductivity - µmhos	183	360	
Temperature - C°	23.7	22.8	
Lithium - mg/l	0.09	0.20	
Sulfite - mg/l	< 0.03	< 0.03	
Cyanide - mg/l	0.16	0.53	
BLANK - MATTAPEAKE			
pH	4.50	4.69	
Conductivity - µmhos	55	200	
Temperature - C°	22.6	23.0	
Lithium - mg/l	0.016	0.023	
Sulfite - mg/l	0.04	0.06	
Cyanide - mg/l	< 0.13	< 0.13	
BLANK - HAGERSTOWN			
pH	6.05	5.96	
Conductivity - µmhos	106	305	
Temperature - C°	22.3	23.1	
Lithium - mg/l	0.033	0.13	
Sulfite - mg/l	< 0.03	< 0.03	
Cyanide - mg/l	< 0.10	· 0.13	

TABLE C-5

PHASE III

LAKELAND WITH DISCHARGED BATTERIES

DATE	TIME	pH	COND. µmhos	TEMP C°	VOLUME ml	CYAN. mg/l	LITH mg/l	SULFITE mg/l
1/27	1335	6.83	225	18.9	300		0.86	0.18
1/28	1410	5.90	220	18.7	470		0.39	0.15
1/29	1300	6.43	6000	19.2	500		607	1,650
1/30	1319	6.39	12,050	18.9	250		1,785	9,900
1/31	1235				150			1
2/1	1330	6.35	12,050	19.2	150		2,035	11,100
2/2	1137				100			
2/3	1407	6.34	10,300	18.9	100	37.8	1,964	9,000
2/4	1409	6.39	9,900	19.6	200	39.0	1,999	11,100
2/5	1136	6.39	6,900	18.8	320	34.0	1,928	10,500
2/6	1258				170			
2/7	1255	6.31	6,700	19.0	165	32.0	1,856	10,200
2/8	0937				100			
2/9	1300	6.80	5,500	18.6	100	27.0	1,750	10,500
2/10	1200				100			
2/11	1342	6.90	9,000	18.9	100	32.0	1,771	10,200
2/12	1343				100			
2/14	1301	6.83	10,600	19.3	200		1,699	8,700
2/15	1341	7.00	7,800	19.0	200	17.0	1071	6,000
2/16	1342	7.31	3,150	19.3	250	4.0	343.9	1,255
2/17	1340	7.31	2,000	18.7	200	1.1	168.4	26.3
2/18	1353	7.21	1,310	19.9	210	0.70		132.0
2/18	1310	6.30	1,000	17.7	200	0.82	77.2	73.5
2/20	1145	7.28	870	19.6	210	0.92	58.2	36.0
2/21	1334	7.26	760	19.9	315			
2/22	1339	7.25	465	18.8	320	0.92	31.6	54.0
2/23	1346	7.20	360	17.6	200			
2/27					600			
2/28					85			
3/2	1315				10			

OPENED 1/26

1700

TABLE C-6

PHASE III

LAKELAND WITH LIVE BATTERIES

DATE	TIME	pH	COND. µmhos	TEMP. C°	VOLUME ml	CYAN mg/l	LITH. mg/l	SULFITE mg/l
1/23	1105							
1/24	1105	5.55	130	19.8	600	0.005	0.042	0.15
1/25	1005	5.63	125	22.0	430	0.005	0.028	0.15
1/26	11008	5.85	205	21.6	275	0.006	0.007	0.12
1/27	1330	5.83	3210	20.7	500	0.042	336	450
1/28	1406	6.30	12,900	18.9	500	1.40	2,856	11,400
1/29	1300	11.82	22,000	19.1	500	1.20	3,035	9,000
1/30	1316	11.78	19,800	18.4	250	0.84	2,392	7,200
1/31	1230	11.83	17,600	19.1	250	0.86	2,199	6,300
2/1	1330				195			
2/2	1135	11.68	16,300	18.9	100	0.77	1,821	4,800
2/3	1405	11.60	14,300	19.2	200	0.49	1,499	3,900
2/4	1401	11.52	11,600	19.3	200	0.33	1,035	2,580
2/5	1132				170			
2/6	1253	11.45	9,000	18.7	165	0.21	771	1,590
2/7	1254				120			
2/8	0932	11.35	7,400	19.0	140	0.15	493	540
2/9	1300				40			
2/10	1200				40			
2/11	1341				40			
2/12	1342				40			
2/14	1300				40			
2/15	1335	11.26	4,150	18.6	40	0.11	3.36	150
2/16	1337				50			
2/17	1337	11.20	3,700	18.9	170	0.05	259.6	50.0
2/18	1352				180			
2/19	1309	11.00	3,050	20.1	150	0.04	217.5	32.0
2/20	1133	11.12	2,920	19.8	250	0.03	182.5	18.0
2/22	1341	11.00	1,890	19.60	300	< 0.02	101.7	9.6
2/23	1342				130			
2/27								
2/28					190	98.2		12.5
3/2	1313	10.85	1,150	19.80	20	80.7		13.5

TABLE C-7

PHASE III

LAKELAND CONTROL

DATE	TIME	pH	COND. µmhos	TEMP. C°	VOL. ml	CYAN mg/l	LITH mg/l	SULFITE mg/l
11/23								
11/24	1105				35			
11/25	1025				25			
11/26	1116				90			
1/27	1340	6.89	260	19.0	400	0.006	0.014	0.15
1/28	1420	6.49	260	19.3	335	0.014	0.43	0.09
1/29	1310	6.54	430	18.7	350	0.050	1.96	0.15
1/30	1325	6.18	250	18.5	290	0.012	0.13	0.12
1/31	1235	6.7	250	19.1	250	0.016	0.81	0.13
2/1	1340	6.71	250	18.7	250	0.033	0.07	0.10
2/2	1138	6.70	250	18.6	250	0.14	0.028	0.10
2/3	1410	6.71	250	19.1	250	0.061	0.035	0.09
2/4	1410	6.68	310	18.1	250	0.074	1.16	0.11
2/5	1139	6.61	250	18.6	250	0.075	0.88	0.11
2/6	1259	6.75	260	18.7	250	0.050	1.95	0.23
2/7	1258	6.81	230	19.0	250	0.111	3.45	0.18
2/8	0938				160			
2/9	1300	6.90	180	18.7	150	0.012	< 0.005	0.18
2/10	1203				100			
2/11	1346	7.00	210	18.8	100	0.088	3.35	5.1
2/12	1345				100			
2/14	1305	7.05	200	18.6	200	0.024	0.81	3.48
2/15	1345				100			
2/16	1348	7.20	220	20.3	100	0.01	0.98	1.05
2/17	1345				100			
2/18	1356	6.60	205	20.1	120	0.007	0.25	0.20
2/19	1312				100			
2/20	1148				50			
2/21		6.85	200	19.9	160			
2/22	1350				50			
2/23	1342				50			
2/28		6.80	210	19.8	150	< 0.005	< 0.005	0.09
3/2	1316				15			
3/5	1537				10			

TABLE C-8

PHASE III

MATTAPEAKE WITH DISCHARGED BATTERIES

DATE	TIME	pH	COND. µmhos	TEMP. C°	VOLUME ml	CYAN mg/l	LITH mg/l	SULFITE mg/l
1/27	1400				150			
1/28	1400	6.38	450	19.7	50	0.010	0.028	0.03
1/29	1300				25			
1/30	1311				30			
1/31	1230				25			
2/1	1330				15			
2/2	1130				15			
2/3	1401				25			
2/4	1400				25			
2/5	1122	6.19	282	18.8	25	0.008	0.64	< 0.03
2/6	1251				25			
2/7	1250				25			
2/8	0931				25			
2/9	1300				25			
2/10	1200				25			
2/11	1330				25			
2/12	1339				25			
2/14	1257				15			
2/15	1331				15			
2/16	1333	7.71	365	19.8	15	< 0.005	0.25	< 0.06
2/17	1336				15			
2/18	1351				10			
2/19	1305				10			
2/20	1130				10			
2/21	1333				10			
2/22	1337				10			
2/23	1341				10			
2/28	1500				35			
3/2	1311				10	0.006		
3/5	1517	7.47	434	19.2	85		0.26	< 0.06

TABLE C-9

PHASE III

MATTAPEAKE WITH LIVE BATTERIES

DATE	TIME	pH	Conductivity µmhos	Temp. C°	Volume ML	Cyan. mg/1	Lith. mg/1	Sulfite mg/1
1/23	1100							
1/24	1105				75			
1/25	1005				75			
1/26	1107				30			
1/27	1347	6.71	490	19.1	30	0.019	0.02	0.03
1/28	1400				30			
1/29	1300				20			
1/30	1310				10			
1/31	1230				10			
2/1	1330				10			
2/2	1130				10			
2/3	1400				10			
2/4	1350				10			
2/5	1121				10			
2/6	1250				10			
2/7	1250				10			
2/8	0930				10			
2/9	1300				10			
2/10	1200				10			
2/11	1330				10			
2/12	1335				10			
2/14	1253				10			
2/15	1330				10			
2/16	1331	8.12	710	19.8	10		10.2	0.9
2/17	1336				15			
2/18	1350				10			
2/19	1305				10			
2/20	1130				10			
2/21	1332				10			
2/22	1336				10			
2/23	1340				10			
2/28	1500				30			
3/2	1310				10			

TABLE C-10

PHASE III

MATTAPEAKE CONTROL

DATE	TIME	pH	COND. umhos	TEMP C°	VOLUME ml	CYAN mg/l	LITH mg/l	SULFITE mg/l
1/24	1105				175			
1/25	1010	5.60	520	14.7	175	0.024	0.68	0.03
1/26	1108				35			
1/27	1400				35			
1/28	1405				30			
1/29	1300				20			
1/30	1312	6.30	520	18.3	80	0.008	1.55	0.25
1/31	1230				50			
2/1	1330				50			
2/2	1130				50			
2/3	1402	5.63	410	19.1	50	0.007	0.99	< 0.03
2/4	1401				50			
2/5	1131				50			
2/6	1252				50			
2/7	1251	6.81	385	18.6	50	0.010	0.81	0.04
2/8	0931				50			
2/9	1300				50			
2/10	1202				50			
2/11	1331	6.81	365	18.9	50	0.42	11.55	1.5
2/12	1340				50			
2/14	1258				100			
2/15	1332	6.78	360	19.0	50	< 0.005	0.16	< 0.03
2/16	1336				50			
2/17	1336				40			
2/18	1352				50			
2/19	1306	6.52	264	17.6	50	< 0.005	0.82	< 0.06
2/20	1130				50			
2/21	1334				50			
2/22	1336	6.51	275	19.6	50	< 0.005	< 0.005	< 0.06
2/28	1500	6.50	263	19.8	300	0.006	< 0.005	< 0.06
3/2	1312				100			
3/5	1319	6.55	182	19.4	200	0.006	< 0.005	< 0.06

TABLE C-11

PHASE III

HAGERSTOWN WITH DISCHARGED BATTERIES

DATE	TIME	pH	COND. umhos	TEMP C°	VOL. ml	CYAN. mg/1	LITH mg/1	SULFITE mg/1
1/27	1402				30			
1/28	1422				25			
1/29	1321				25			
1/30	1334				25			
1/31	1241				15			
2/1	1357				30			
2/2	1141				30			
2/3	1415	6.89	950	18.6	30	0.02	1.0	0.09
2/4	1416				30			
2/5	1140				30			
2/6	1301				30			
2/7	1301				30			
2/8	0945				30			
2/9	1300				25			
2/10	1205				20			
2/11	1351	7.83	670	19.9	20	0.005	0.13	0.06
2/12	1343				20			
2/14	1306				40			
2/15	1386				20			
2/16	1341				20			
2/17	1347				90			
2/18	1358	7.90	680	20.3	80	< 0.005	0.18	< 0.06
2/19	1312				50			
2/20	1150				40			
2/21	1337				40			
2/22	1353				49			
2/23	1350				45			
2/28	1600	7.92	6.85	20.0	120	< 0.005	< 0.005	< 0.06
3/2	1321				85			

Opened 1/26
1700

TABLE C-12

PHASE III

HAGERSTOWN WITH LIVE BATTERIES

DATE	TIME	pH	COND µmhos	TEMP. C°	VOLUME ml	CYAN mg/l	LITH mg/l	SULFITE mg/l
1/23	1105							
1/24	1105				75			
1/25	1005				75			
1/26	1119	6.82	1180	19.8	70	0.009	< 0.005	0.09
1/27	1400				60			
1/28	1421				35			
1/29	1320				15			
1/30	1333				40			
1/31	1240				40			
2/1	1352	6.99	1190	19.1	40	0.011	0.13	0.09
2/2	1140				35			
2/3	1415				35			
2/4	1416				30			
2/5	1139				30			
2/6	1259				30			
2/7	1259				30			
2/8	0940	7.00	1200	18.3	30	0.014	2.0	0.18
2/9	1300				30			
2/10	1204				30			
2/11	1349				30			
2/12	1347				30			
2/14	1307				40			
2/15	1346				30			
2/16	1350				30			
2/17	1346	7.40	910	20.1	50	0.008	1.09	0.09
2/18	1357				45			
2/19	1311				55			
2/20	1149				50			
2/21	1337				45			
2/22	1352	7.19	780	20.2	50	< 0.005	0.35	0.09
2/23	1346				50			
2/28					20			
3/2	1320				30			

TABLE C-13

PHASE III

HAGERSTOWN CONTROL

DATE	TIME	pH	COND. µmhos	TEMP. C°	VOL. ml	CYAN mg/l	LITH mg/l	SULFITE mg/l
11/23								
11/24	1105				50			
11/25	1030				50			
1/26	1120	6.79	1410	19.2	150	0.015	0.014	0.09
1/27	1405				165			
1/28	1426	6.79	1200	18.7	145	0.016	0.084	0.05
1/29	1322				150			
1/30	1335	6.79	1250	18.9	160	0.021	0.32	0.06
1/31	1342				160			
2/1	1358	6.69	1180	18.7	150	0.025	0.18	0.06
2/2	1143				125			
2/3	1420	7.05	870	18.9	135	0.022	0.37	0.03
2/4	1417				125			
2/5	1141	6.95	820	19.2	125	0.028	0.65	0.09
2/6	1302				125			
2/7	1302	7.10	860	18.7	125	0.025	0.73	0.07
2/8	0946				125			
2/9	1300	7.5	700	18.9	125	0.004	< 0.005	0.06
2/10	1205				125			
2/11	1356	7.54	710	19.9	125	0.002	0.09	0.06
2/12	1345				125			
2/14	1307	7.60	705	18.7	250	< 0.005	< 0.005	0.05
2/15	1348				125			
2/16	1342	6.98	780	19.2	125	0.008	0.14	0.08
2/17	1348				135			
2/18	1359	7.00	720	19.6	135	0.022	0.62	< 0.06
2/19	1313				135			
2/20	1151	7.12	700	19.4	140		0.28	0.06
2/21	1340				135			
2/22	1356	7.05	710	19.6	135	0.008	0.03	0.09
2/23	1347				135			
2/28	1508				140			
3/2	1322	7.00	715	20.2	150	< 0.005	< 0.005	< 0.06
3/5	1544	7.10	705	19.2	350	< 0.005	< 0.005	< 0.06

TABLE C-14

SOIL CHARACTERIZATION[1]

	Vermiculite	Mica	Kaslimite	Quartz
Mattapeake	xx	x	18%	
Hagerstown	xx		xx	
Lakeland			xx	xx

	Percent Organic Material	Percent CLAY	pH	mg/100g Cation Exchange Capacity
Mattapeake Silty Loam	1.93	25.2	5.6	10.2
Hagerstown Silty Clay Loam	2.50	39.5	6.8	14.7
Lakeland Sandy Loam	0.90	12.0	6.4	3.0

[1] Information provided by
Dr. E. Noolson
U.S. Department of Agriculture
Pesticide Research Group
Beltsville, Maryland

TABLE C-15

VOLUME LOG FOR HAGERSTOWN

SOIL LEACHATE COLUMNS

DATE	LIVE Time	LIVE Vol.	LIVE Δ Vol.	CONTROL Time	CONTROL Vol.	CONTROL Δ Vol.	DISCHARGED Time	DISCHARGED Vol.	DISCHARGED Δ Vol.
JAN.23	1105	Opened							
24	1105	75	75	1105	50	50			
25	1005	150	75	1030	100	50			
26	1119	220	70	1120	250	150	1700	Opened	
27	1400	280	60	1405	415	165	1402	30	30
28	1421	315	35	1426	560	145	1422	55	25
29	1320	330	15	1322	710	150	1320	80	25
30	1330	370	40	1335	870	160	1334	105	25
31	1240	410	40	1342	1030	160	1241	120	15
FEB. 1	1352	450	40	1358	1180	150	1357	150	30
2	1140	485	35	1143	1305	125	1141	180	30
3	1415	520	35	1420	1440	135	1415	210	30
4	1416	550	30	1417	1565	125	1416	240	30
5	1139	580	30	1141	1690	125	1140	270	30
6	1259	610	30	1302	1815	125	1301	300	30
7	1259	640	30	1302	1940	125	1300	330	30
8	0940	670	30	0946	2065	125	0945	360	30
9	1300	700	30	1300	2190	125	1300	385	25
10	1204	730	30	1205	2315	125	1205	405	20
11	1349	760	30	1356	2440	125	1351	425	20
12	1347	790	30	1345	2565	125	1343	445	20
13									
14	1307	890	40	1307	2815	250	1306	485	40
15	1346	860	30	1348	2940	125	1346	505	20
16	1350	890	30	1342	3065	125	1341	525	20
17	1346	940	50	1348	3200	135	1347	615	20
18	1357	985	45	1359	3335	135	1358	695	80
19	1311	1040	55	1313	3470	135	1312	745	50
20	1149	1090	50	1151	3610	140	1150	785	40
21	1337	1135	45	1340	3745	135	1337	825	40
22	1352	1125	50	1356	3880	135	1353	865	40
23	1346	1235	50	1351	4015	135	1350	910	45
24									
25									
26									
27					4615	600			
28	1500	1255	20	1508	4750	135	1503	1030	120
Mar. 1		1255			4750			1030	
2	1320	1285	30	1322	4900	150	1321	1115	85
5	1540	1380	95	1544	5250	350	1542	1180	65
8	1107	1435	55	1108	5650	400	1109	1240	60

TABLE C-15

VOLUME LOG FOR LAKELAND
SOIL LEACHATE COLUMNS

DATE	LIVE Time	LIVE Vol.	LIVE ΔVol.	CONTROL Time	CONTROL Vol.	CONTROL ΔVol.	DISCHARGED Time	DISCHARGED Vol.	DISCHARGED ΔVol.
JAN.23	1105	Opened							
24	1105	600	600	1105	35	35			
25	1005	1030	430	1025	60	25			
26	1108	1305	275	1116	150	90	1700	Opened	
27	1330	1805	500	1340	550	400	1335	300	300
28	1406	2305	500	1420	885	335	1410	770	470
29	1300	2805	500	1310	1235	350	1300	1270	500
30	1316	3055	250	1325	1525	290	1319	1520	250
31	1230	3305	250	1235	1775	250	1235	1670	150
FEB. 1	1330	3500	195	1340	2025	250	1330	1820	150
2	1135	3600	100	1138	2275	250	1137	1920	100
3	1405	3800	200	1410	2525	250	1407	2020	100
4	1401	4000	200	1410	2775	250	1409	2220	200
5	1132	4170	170	1139	3025	250	1136	2540	320
6	1253	4335	165	1258	3275	250	1258	2710	170
7	1254	4455	120	1258	3525	250	1255	2875	165
8	0932	4575	140	0938	3685	160	0937	2975	100
9	1300	4635	40	1300	3835	150	1300	3075	100
10	1200	4675	40	1203	3935	100	1200	3175	100
11	1341	4715	40	1346	4035	100	1342	3275	100
12	1342	4755	40	1345	4135	100	1343	3375	100
13									
14	1300	4775	80	1305	4335	200	1301	3575	200
15	1335	4875	40	1345	4435	100	1341	3775	200
16	1337	4925	50	1342	4535	100	1348	4025	250
17	1337	5075	170	1340	4635	100	1345	4225	200
18	1352	5275	180	1353	4755	120	1356	4435	210
19	1309	5425	150	1310	4855	100	1312	4635	200
20	1133	5675	250	1145	4705	50	1148	4845	210
21	1334	5775	300	1834	5065	160	1335	5160	315
22	1341	6275	300	1339	5115	50	1350	5480	320
23	1342	6405	130	1342	5165	50	1346	5680	200
24									
25									
26									
27					5165			6280	600
28	1501	6295	190	1502	5317	1500	1502	6365	85
Mar. 1		6295			5315			6365	
2	1313	6315	20	1316	5330	15	1315	6375	10
5	1530	6635	320	1537	5340	10	1535	6385	10
8	1102	7035	400	1106	5350	10	1103	6375	400

TABLE C-15

VOLUME LOG FOR MATTAPEAKE
SOIL LEACHATE COLUMNS

DATE	LIVE Time	LIVE Vol.	LIVE ΔVol.	CONTROL Time	CONTROL Vol.	CONTROL ΔVol.	DISCHARGED Time	DISCHARGED Vol.	DISCHARGED ΔVol.
JAN.23	1100	Opened							
24	1105	75	75	1105	175	175			
25	1005	150	75	1010	350	175			
26	1107	180	30	1108	385	35	1700	Opened	
27	1347	220	30	1400	420	35	1400	150	150
28	1400	250	30	1405	450	30	1400	200	50
29	1300	270	20	1300	470	20	1300	225	25
30	1310	280	10	1312	550	80	1311	255	30
31	1230	290	10	1230	600	50	1230	280	25
FEB. 1	1330	300	10	1330	650	50	1330	295	15
2	1130	310	10	1130	700	50	1130	310	15
3	1400	320	10	1402	750	50	1401	335	25
4	1350	330	10	1401	800	50	1400	360	25
5	1121	340	10	1131	850	50	1122	385	25
6	1250	350	10	1252	900	50	1251	410	25
7	1250	360	10	1251	950	50	1250	435	25
8	0930	370	10	0931	1000	50	0931	460	25
9	1300	380	10	1300	1050	50	1300	485	25
10	1200	390	10	1202	1100	50	1200	510	25
11	1330	400	10	1331	1150	50	1330	535	25
12	1335	410	10	1340	1200	50	1339	560	25
13									
14	1253	430	20	1258	1300	100	1257	610	50
15	1330	440	10	1332	1350	50	1331	635	25
16	1331	450	10	1336	1400	50	1333	650	15
17	1336	465	15	1336	1440	40	1336	665	15
18	1350	475	10	1352	1490	50	1351	675	10
19	1305	485	10	1306	1540	50	1305	685	10
20	1130	495	10	1130	1570	50	1130	675	10
21	1332	505	10	1334	1640	50	1333	705	10
22	1336	515	10	1336	1690	50	1337	715	10
23	1340	525	10				1341	725	10
24									
25									
26									
27									
28	1500	555	30	1500	1990	300	1500	760	35
MAR. 1		555			1990			760	
2	1310	565	10	1312	2090	100	1311	770	10
3									
4									
5	1511	565	-	1519	2290	200	1517	855	85
6									
7									
8	1100	575	10	1101	2420	130	1100	885	30

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